Effect of different tree species on soil quality parameters in forest plantations of Kyrgyzstan

Einfluss verschiedener Baumarten auf die Parameter der Bodenqualität unter Aufforstungen in Kirgisien

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1 Introduction

Kyrgyzstan is a mountainous country embraced in the east by the Tian-Shan and in the north by the Pamira-Alay mountain systems. The landscape, in combination with other natural factors, potentially predisposes the mountainous regions of the country to high erosion (Aidarilev et al., 2001). Even though the forest-covered area in Kyrgyzstan approximates only 4 % of the total area, it plays a significant role in soil, water and landslide protection. The intensive exploitation of the forest, especially the harvesting of fir-trees over long and extended period, posses a great threat to the environment. The current and future status of forestry conservation has become a topic of general discussion among the scientific community. In Kyrgyzstan some forested areas have already been identified to be distressed due to the loss of biological activity (Aidarilev et al., 2001).

The general political goal is now focused on the preservation of forests, namely to improve their stability, rational usage and reproduction in order to harmonise conflicts between the forestry sector and ecological concerns. An effective and efficient way to enhance forest unit area productivity is to increase afforestation by the introduction of other tree species among Kyrgyzstan fir mono-species forest (Gan, 1987).

Generally, investigations on the relationship between forest and soil refer to the influence of soil on the distribution and growth performance of the vegetation. Such research is mainly concerned with processes of podzol formation and the influence on forest establishment, growth and sustenance (Deconinck, 1983; Mokma et al., 1982).

Earlier research work revealed that for increasing forest productivity the improvement of forest soil properties has also to be considered. Ovington (1953) for instance reported that only having the right assortment of forest species during afforestation could save fertility of forest soils on the British islands.

Concerning the problems of soil formation in coniferous forests, Zonn (1954a) emphasised the significance of physical and geographical features of sites and the need for monitoring under different tree species. The interaction between soil and forest vegetation has been recognized by a famous russian soil scientist, Dokuchaev (1899). Thus, he established a foundation with the hope that in the future not only differences between steppe and forest soils will be distinguished but also between soils under different forest types.

The effect of podzol formation in wet and cold climates is well established in the scientific literature (Sokolov et al., 1990; Schatezel and Isard, 1996; Olsson and Troedsson, 1990). Assertions about podzoling effects of fir are based on observations about changes in the morphological features of the soil profile in connection with settlement of a fir. Under the fir a clearly visible podzol layer is reshaped on which it is possible to establish the progression of podzol, as it was carried out by Dobrovols'skiy et al. (1993), Clayden et al. (1990), DeConick and Righi (1983) and Evans and Cameron (1985). Even in conditions of boreal zone, the process of podzol formation under fir is developed with identical intensity. However, it is not everywhere clearly expressed (Zonn, 1978).

An indispensable condition for podzol formation is the decomposition of forest litter under anaerobic conditions with the progression of reduction processes and formation of acids, which deplete the nutrient supply. The speed of podzol formation is influenced by the soil-forming rocks, the fertility of the soil through the litter component and in particular by the calcium content. Therefore, the fir podzol soil cannot be found everywhere. Thus, in the northern part of Russia under fir forests, on eluvia of chalkstones and marls, humus-carbonaceous non-podzol soils have developed (Zonn, 1978; Grigor'ev, 1979). Iarkov (1954) also reported that on sandy soils during high humidity, the anaerobic conditions of podzoling under coniferous forests might not take place. Also in those bioclimatic conditions where decomposition of litter takes place slowly, the fir does not facilitate the podzoling of the soil (Zonn, 1950; Zaicev, 1965; Samusenko and Kojekov, 1982).

The influence of fir forests on soil formation is different under mountainous conditions compared to valley conditions. In the mountainous region, the soil formation process depends on the relief, namely the exposure and steepness of slopes and on the climatic and microclimatic regime of slopes.

The most detailed studies on the influence of forest plantations on soil were conducted in steppe-forest and steppe zones, especially in the west part of the former USSR (Zonn, 1954b; Rozanov, 1955; Zemlynickii, 1954). The literature cited above indicates that forests in steppe and forest-steppe have no podzol soils. Forest plantations in these conditions form a special soil with an increased fertility. Studies of Remezov (1955) revealed that deciduous species in the sub-band of coniferous-deciduous forests promote the formation of brown-forest soils characterised by a maximal expressiveness of the turf process and synthesis of secondary minerals in the upper soil layers.

The influence of forest plantations on soil under natural conditions depends on the ecological and biological properties of plantations (Noble and Randall, 2003; Barnes et al., 1998). The forest plantations are characterised among others by the quality and quantity of forest falls (litter), the microclimate occurrence in plantations, the progression of microflora, and the spread of root systems in soil. All these properties define the specificity of soil formation under the "soil–forest" cycle. Therefore, different species of trees under natural conditions will promote interferences and changes in the soil formation process.

The main objectives of the present research work were:

I. To assess the composition of the forest litter under the investigated plantations;

II. To quantify the influence of birch, fir, pine and larch plantations on changes in the vegetative cover;

III. To assess the influence of different trees on the chemical and hydrological properties of soils;

IV. To evaluate the soil biological activity under the influence of different trees.

2 Material and methods

2.1 Experimental sites

Experiments were conducted on the natural boundary Jylandy in the Ak-Suu LOH area (Kyrgyzstan) in 2000-2002 (Fig. 2.1). Ak-Suu LOH is in the northeast part of Issyk-Kul area (Fig. 2.1). Since 1949, different trees were planted on more than 600 ha on the Ak-Suu LOH territory. Ak-Suu LOH was officially organised in 1956 as a plot for the Forest Institute with the purpose of carrying forest experiments in the belt of the fir forest.

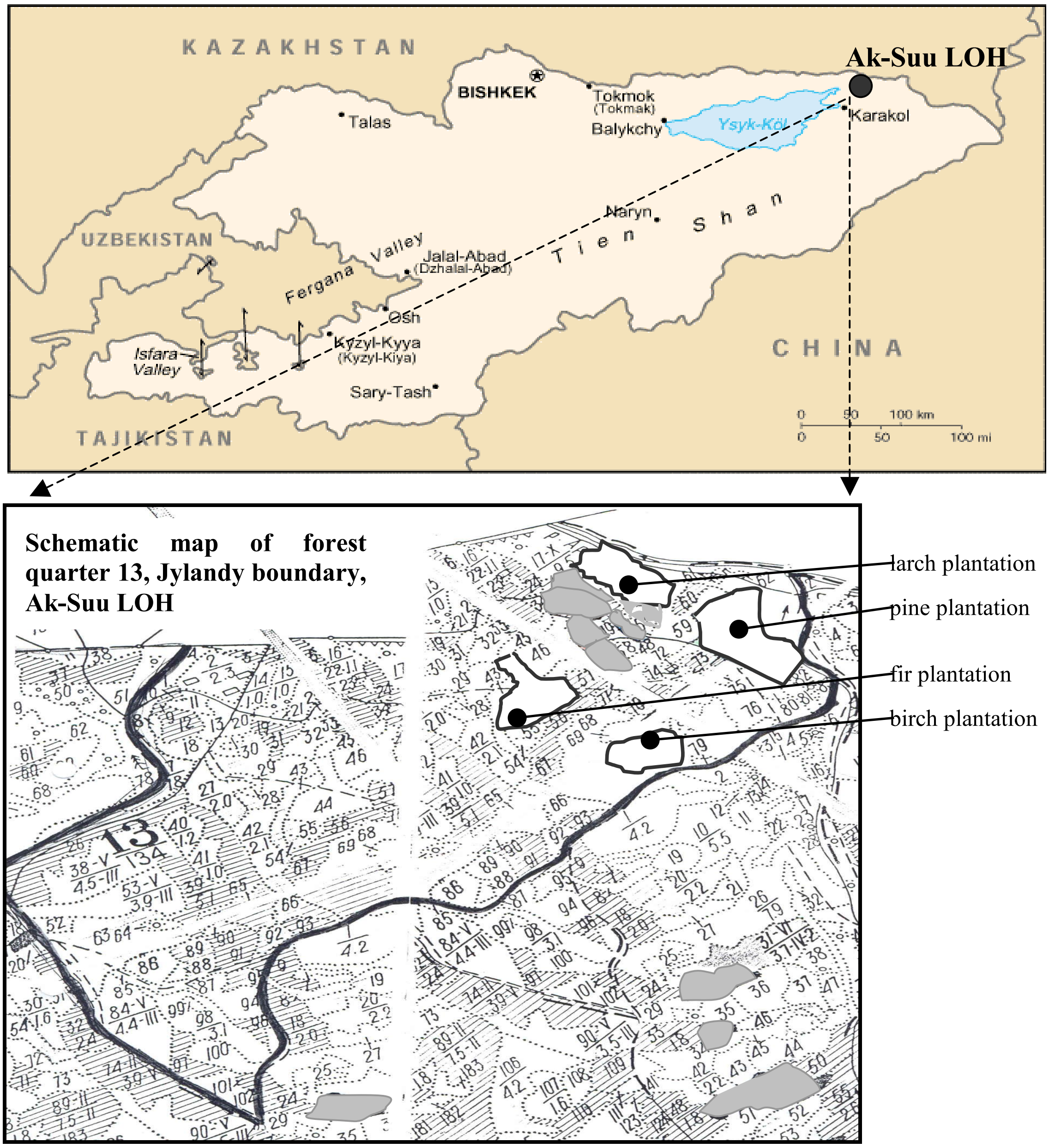


Fig. 2.1: Location of the sampling site, forest quarter 13, Jylandy boundary, Ak-Suu LOH, Northern Kyrgyzstan, Central Asia.

2.1.1 Geomorphology of the site

The natural boundary of Jylandy is represented by a split watershed between two inflow rivers, Zindan and Jylandy. The relief is formed by many gorges, which cut the mountain slopes. The steepness of slopes is variable being dominated by slopes with an angle of inclination of more than 20°. The exposition of the point is to all directions.

The natural boundary is formed of solid rocks, less exposed to weathering processes. As a result, steep slopes are predominantly formed. In the southwest part of the experimental site, where ancient solid formations are covered by tertiary sand-clay depositions, the relief acquired more smooth features. Therefore, slopes less than 20° predominate in this part. Flat sites in the natural boundary are found more on watersheds formed by clefts. In the highest part of the natural boundary a lot of flat sites are presented, which often are bogged by soil inner waters. Seldom, bogged lands are also observed on lower levels.

2.1.2 Lithology

From the geological point of view, the investigated territory is formed of bed rocks such as ancient granites, carbon chalkstones and crimson retinue lime argillaceous shitts. The latter is the main soil-forming bed rock on the territory. Eluvial soil horizons have a clay texture. Large areas of chalkstones are rare noticed in the investigated territory. Only on the east slope of the river Ak-Suu and on the southeast slope of Zindan River, chalkstones are the predominately bed rocks.

As already mentioned, the southwest part of the territory is bedded with tertiary sand-clay depositions. They consist of sand-clay of “brick-red” colour with gravels. The soil formed on these depositions has a heavy-loam texture.

2.1.3 Soil-forming rocks

Depending on the relief, soil-forming rocks are formed by eluvial, eluvial-deluvial or deluvial depositions. The soil-forming rocks formed by deluvial deposition have a homogeneous composition and loess. The eluvial formation is predominately found in the upper third of slopes and flat parts, excepting parts of the investigated territory formed by deluvial deposition of soil rocks. The natural eluvial formation is largely dependent on slope expositions. As a rule, on southern expositions and close to them, the eluvial soil horizons are hardly washed off and therefore remain a lot of stones. Additionally, on the investigated territory, slopes with south and southeast expositions are more exposed to erosion. On northern slopes, a thick eluvial soil layer covers the roughly gravel-eluvial mass. The eluvial-deluvial depositions are common to middle part slopes, whereas deluvial depositions are placed on the lower third and bottom slopes. The deluvial and the eluvial-deluvial depositions contain small amounts of bed rocks.

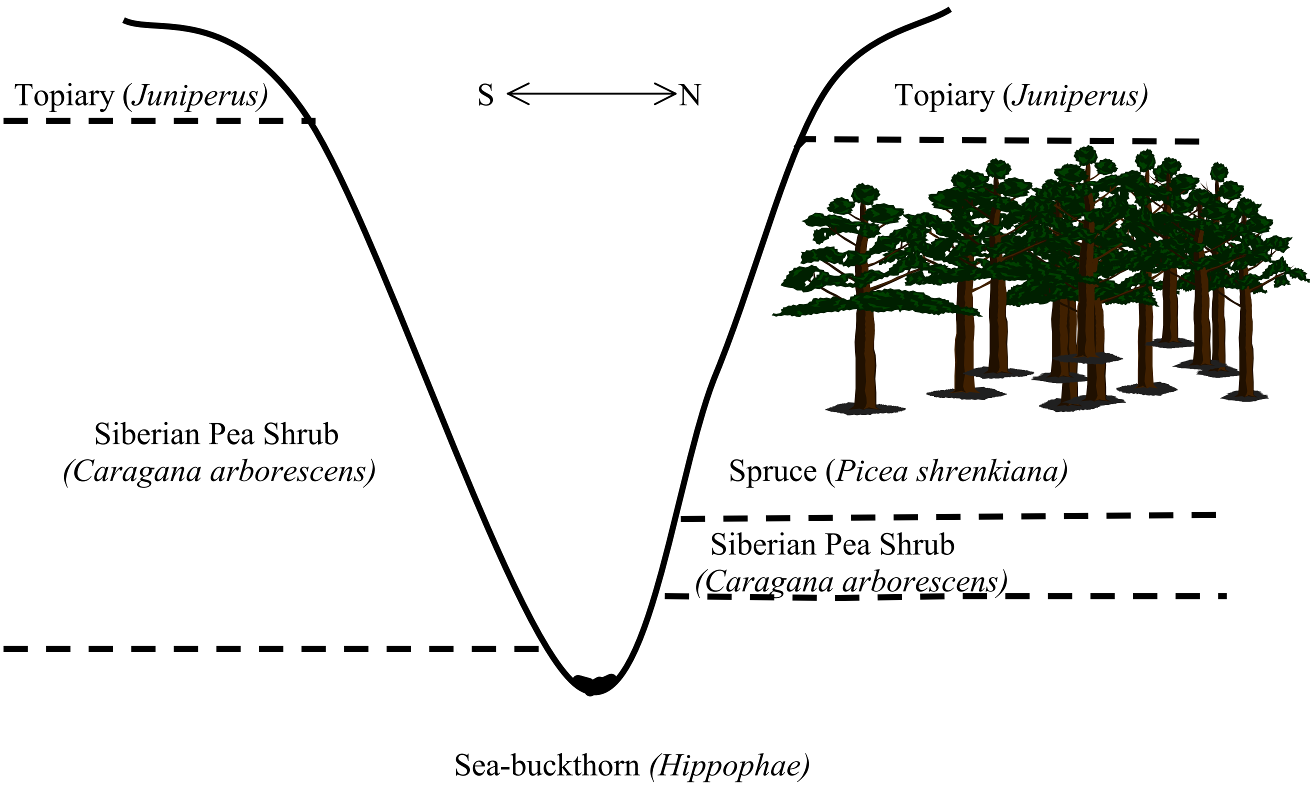
The special feature of the natural boundary prevents the soil against erosion. On slopes with high steepness, full soil profiles with a deepness of more than 1 meter are formed. Therefore, the soil depth is only varied on slopes from the top to the lower third part.

2.1.4 Vegetation

The vegetation is closely connected with slope expositions (see schema 1). Fir forest is the basic vegetative group in the natural boundary, which varies with grass-cereal meadows, cereal-grass associations on forest glades or dry-steppe vegetation on southern slopes (see photo 1). The transitional vegetation on southwest slopes also includes meadow and dry-steppe species, and bushes (e.g. *Berberis spec.*, *Rosa canina L*).

Photo 1: Vegetative groups in relation to the slope expositions in the Jylandy boundary (2000)

Fir forest occupies approximately a third part of the natural boundary. They predominate on northern expositions and close to them (north-east, north-west) (see schema 1). The forest is grown on slopes as a discontinuous belt with open areas, avoiding dry places. Therefore, the forest density is low. In the forested area the density of trees is high. As a consequence, the sunlight cannot reach under canopies, preventing therefore the growth of grass vegetation. A thick forest litter covers the soil surface.



Schema 1: Schematic representation of vegetation depending on altitude and slope expositions in the Jylandy boundary

Cereals and grassy associations with tight growth cover forest glades. The coverage of grasslands on the soil surface is 75-80 %. Grasslands with abundant specie varieties are predominating on northern open slope expositions and close to them. On east and southeast slopes the vegetation is different. The coverage of grasslands on these slopes is less than 25-40 % and is mainly represented by sagebrush and steppe species.

2.1.5 Climate

The investigated territory has a strong continental climate. The Issyk-Kul Lake, close to the investigated territory, causes soft climatic conditions. The Issyk-Kul territory is extended from west to the east more than 200 km and the precipitation rates are extremely irregular. The long-term mean annual precipitation in the eastern part is higher than 600 mm, whereas in the western part is about 100 mm. The most important factor for growing fir is the precipitation rate. Fir forest does not grow in regions where precipitation is less than 500 mm (Gan, 1987). Therefore, in the western part of the Issyk-Kul territory fir forest is not growing. Climatic variations (e.g. precipitation rates, temperature) on the investigated territory depend also on altitude. For instance, on the lower boundary of fir forest (1700 m above sea level) the long-term mean annual precipitation is 400-600 mm, while on the upper boundary (2500 m above sea level) is 800-900 mm (Gan, 1987).

Comparing the long-term mean January temperature in the fir forest belt according to altitude, the temperature decreases from 5.3°C to –0.1°C with increasing the altitude from 1800 to 3000 meters above see level. Another characteristic of fir forest in the investigated territory is the coldness of soils (Cheshev et al., 1978). For example, in the upper 1 m soil layer the temperature is between 4-11°C in the warm season (from June till September).

The different hydrothermal regimes of the soil (e.g. coldness, periodic dryness, saturation by ultra-violet rays) cause a weak decomposition of forest fallings (litter) and therefore their conservation and accumulation in the forest and forest plantations as dry-peat forest litter of approximately 20 cm.

Meteorological records during the years of study were provided by the Ak-Suu Experimental Station, situated at 1950 meters above sea level in the Jylandy boundary. During experimentation, the mean annual temperature was about 3.6°C (Tab. 2.1). The long-term mean annual temperature is 4.7°C (Cheshev et al., 1978; Matveev, 1973).

Tab. 2.1: Average monthly air temperature (°C) at the experimental site in the Jylandy boundary during three years

Year	**Temperature (C°)**												**Mean**
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2000	-8.5	-4.9	-3.6	0.9	9.8	11.6	15	13.8	7.8	4.1	-2.5	-6.0	3.1
2001	-8.1	-8.4	-3.3	6.4	10.6	11.1	13.9	14.7	10.1	3.2	-2.2	-5.8	3.5
2002	-9.4	-4.8	0.2	5.2	9.1	13.5	15.7	13.5	9.5	3.6	-0.9	-5.4	4.1

The long-term mean annual precipitation for Jylandy is 638 mm (Cheshev et al., 1978; Matveev, 1973). During the investigated period, precipitation records were 514 mm, 770 mm and 671 mm for the first, second and third year, respectively (Tab. 2.2). The precipitation rate was higher in the spring-summer period, its value exceeding half of the annual rate. Therefore, the precipitation rate favours the growing of forest and grassy vegetation.

Tab. 2.2: Monthly precipitation amounts (mm) on the experimental site in the Jylandy boundary during three years

Year	**Precipitations (mm)**												**Sum**
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2000	16	7	23	27	105	59	59	74	45	56	26	17	514
2001	62	44	21	43	75	91	86	68	112	127	24	17	770
2002	17	25	20	67	68	26	117	11	126	109	15	70	671

2.2 Selection and description of plantations

For analysing the influence of birch, fir, pine and larch trees on the mountain soil, plantations were chosen according to the following criteria:

a) the soil growing conditions were typical for belt fir forest;

b) the plantations were of the same age (approximately 50 years old) and with known history of their creation;

c) the plantations were located not far away from each other;

the control glades (open areas) were placed near plantations, having therefore identical altitude, relief and soil-forming rocks (see photo 2).

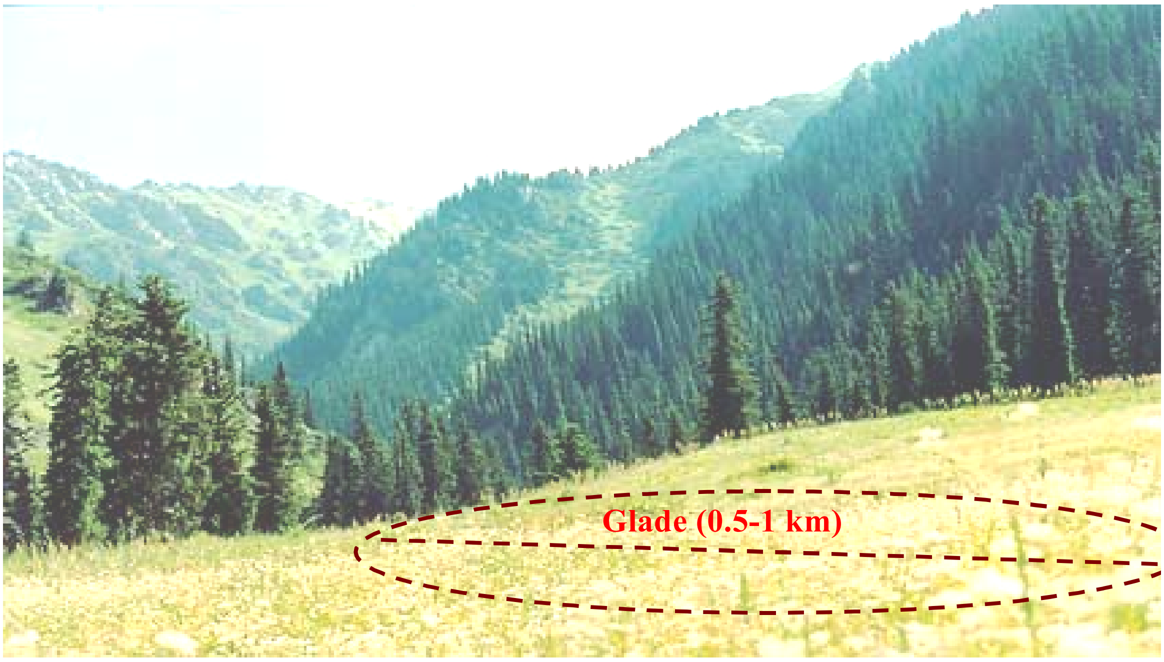


Photo 2: Control glade (open area) near a plantation with identical altitude, relief and soil forming rocks (Jylandy, 2000)

Forest taxation indices

Forest taxation indices were taken from the forest catalogues of Ak-Suu LOH (LOH-Forest Experimental Plot). The last taxation was in 2000. The classification of the investigated plantations according to the forest taxation is listed in table 2.3.

Tab. 2.3: Forest taxation indices of the investigated plantations in the Jylandy boundary (according to Forest Taxation Service in Bishkek, Kyrgyzstan)

Trees	**Birch** *(Betula pendula)*	**Fir** *(Picea shrenkiana)*	**Pine** *(Pinus silvestris)*	**Larch** *(Larix sibirica)*
Bonitet*	I	I	I	I
Mean diameter of trunks (cm)	20	20	24	22
Mean height of trees (m)	17	17	17	16
Area of plantations (ha)	0.9	1.0	2.4	1.5
Age (years)	50	50	50	50
Density	0.8	0.8	0.8	0.8

note: *quality of forest productivity measured on a scale of I-V (I-being the highest); it is calculated as a qualitative value by the height of trees reached after a specific number of years.

All the investigated plantations are located on northeast slopes. Pine and larch plantations were grown close to each other and have an identical slope (25-30°). Birch and fir plantations are grown on the same ranges (10-15°) (see Fig. 2.1).

2.3 Field analysis

2.3.1 Geo-botanical analysis

Geo-botanical analysis is accomplished by the Forest Institute, Kyrgyzstan. Particular attention was turned to the following characteristics:

a) description of plantations and history of their creation;
b) description of floristic composition in plantations and control glades by the Drude scale (Tab. 2.4).

Tab. 2.4: Drude scale rating of floristic composition (Flint et al., 2002)

Scale rating	Description
Soc (socialis)	Dominant plant species; > 90 % coverage
Cop3 (coptosal)	Very abundant; 70-90 % coverage
Cop2 (coptosal)	Many individuals; 50-70 % coverage
Cop1 (coptosal)	30-50 % coverage
Sp (sporsal)	Individuals small in number; 10-30 %coverage
Sol (solitarie)	Very few individuals; < 10 % coverage
Un (unicum)	A single individual

2.3.2 Forest litter

Similar subdivisions of forest litter were carried out according to Hesselman (1914), distinguishing three layers:

1) the fresh forest litter fall designated by the letter L, for Litter ;

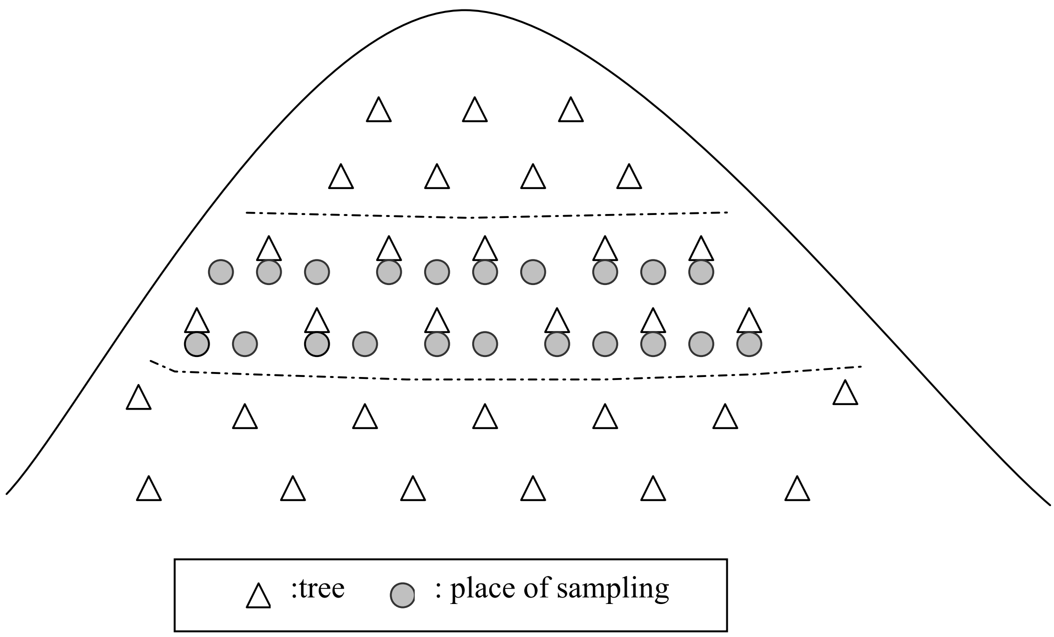
2) the layer of decomposition or fermentation abbreviated by the letter F because of the predominate process of fermentation;

3) the layer where less amorphous organic matter is intermingled with mineral soil constituents labelled H, for humus.

The thickness of forest litter was measured on the line of profiles by setting a ruler near the trunks and between them.

The amount of forest litter: forest litter in plantations were collected from the soil surface within a circle with an area of 500 cm^2. Twenty-one samples were taken from the line of profiles in the summer period (see schema 2). After cleaning the forest litter from soil particles, they were air-dried and weighted. The amount of forest litter was calculated according to the following formula:

$$\text{Forest litter in plantation (t ha}^{-1}\text{)} = \boxed{\frac{\sum_{21} * 10}{1.05}}$$



Schema 2: Schematic representation of forest litter sampling on the trial plots in the Jylandy boundary

Water holding capacity: for defining the water holding capacity of forest litter, water was poured on the samples for 10 minutes and then the samples were left for soaking during 24 hours. Afterwards the absorbed water was measured.

The fractions of the forest litter (e.g. needles, cones, twigs, branches, moss, leaves, bark, scales, decay, grass) were separated and weighted in each of the collected samples.

2.3.3 Soil

Soil samples were taken in the summer period. The sampling procedure and morphological description of soil profiles were carried out according to Soil Survey (Institute of Soil Science, 1959). The following parameters were analysed in the field: water infiltration capacity, runoff transfer coefficient and dry bulk density.

Water infiltration capacity of soils was carried out by the Burikin or tube method (Burikin, 1956), specially designed for mountain conditions. Three tubes of 20 cm height and 4-5 cm diameter were fixed in the ground, 2-3 cm deep, at distances of 30-50 cm between each other. Then, tubes were filled with water and the infiltrating amount of water was measured during definite time (2, 5, 10, 15, 30, 60 min). The process was repeated three times in other parts of the investigated areas. Finally, the total infiltration (mm) and the speed of infiltration (mm/minute) were calculated.

Runoff transfer coefficient was determined according to the Danilik method (Danilik et al., 1993). The surface runoff was ascertained on the line of profiles in plantations and control glades. The investigated sites were not under the influence of humans and cattle. A special portative instrument, which demands a minor amount of water, was fixed in the soil. Throw a hose, 1 litre of water was poured into the instrument. First, the water reached the water-collector. Then, in the limit-infiltration block, one part of water was absorbed by the soil (subsurface runoff) and another part of water reached the catch-camera. Finally, the volume of water in the catch-camera was measured (surface runoff). The procedure was repeated three times in other parts of the investigated areas.

Dry bulk density was investigated by using soil-sampling cylinders to warrant the removal of undisturbed soil cores. For this purpose, steel cylinders (5 cm diameter, 4 cm height) were bored in the soil (three repetitions). Samples were taken from each horizon and finally air-dried and weighted. The bulk density was calculated according to the formula reported in the literature (Plusnin et al., 1974).

2.4 Chemical analysis

2.4.1 Forest litter

All analytical methods were carried out on air-dried forest litter. The forest litter was fine ground to a particle size < 2 mm using an electrical mill. The analysis of macro- and micronutrients were conducted at the Institute of Plant Nutrition and Soil Science, Federal Agriculture Research Centre, Braunschweig, Germany, whereas ash composition was analysed at the Department of Soil Science, Institute of Geology, Bishkek, Kyrgyzstan. The pH of forest litter was determined at the Forest Institute, Bishkek, Kyrgyzstan. The analytical methods for forest litter analysis are summarised in table 2.5.

Tab. 2.5: Analytical methods of forest litter analysis

Parameter	Method
Ash composition (K, Na, Si, Ti)	Rodin method (Rodin et al., 1968)
Total nitrogen	Kjeldahl method (Arinushkina, 1980)
Macro (Ca, Mg, S, P) and micronutrients (Zn, Fe, B, Mn, Cu)	Aqua regia extraction followed by ICP-AES (DIN EN ISO 11466)
pH	potentiometrically in water suspension (1:25, vv) (Arinushkina, 1980)

2.4.2 Soil

All analytical methods were carried out on air-dried and ground soil (< 2 mm). Soil analyses were conducted in five different laboratories. Total and easy hydrolysed nitrogen were analysed at the Soil Department of “Giprozem” Institution, Bishkek, Kyrgyzstan. Metal oxides (P and K), pH and humus were analysed at the Forest Institute, Bishkek, Kyrgyzstan. The amorphous iron (Fe) content and fractional composition of humus were conducted in the laboratory of the Soil Science Institute, Moscow State University, Moscow, Russia. Total macro and micronutrients were analysed at the Institute of Plant Nutrition and Soil Science, Federal Agriculture Research Centre, Braunschweig, Germany. Soil biological activity was determined at the Institute of Agroecology, Federal Agriculture Research Centre, Braunschweig, Germany. Chemical methods of soil analysis are mentioned in table 2.6 and methods that are not generally used worldwide are described in details in this chapter.

Tab. 2.6: Chemical methods of soil analysis

Parameter	Method
Available P and K	Extraction by $(NH_4)_2CO_3$; Denije method modified by Malugin and Hrenova (Radov et al., 1971)
Total nitrogen	Kjeldahl method (Arinushkina, 1980)
Easy hydrolysed nitrogen	Turin and Kononova method (Radov et al., 1971)
pH	potentiometrically in water suspension (1:2.5, vv) (Arinushkina, 1980)
Amorphous Fe	Vorobeva method (Vorobeva, 1998)
Macro (Ca,Mg,S,P) and micronutrients (Zn,Fe,B,Mn,Cu)	Aqua regia extraction followed by ICP-AES (DIN EN ISO 11466)
Soil microbial biomass and respiration	Infrared gas analysis (Martens et al., 1995)
Total humus	Turin method (Arinushkina, 1980)
Fractional humus composition	Turin and Ponomareva-Plotnikova method (Orlov et al., 1981)

Available phosphorus and potassium were extracted in Machigin solution (Radov et al., 1971). Five grams of soil were placed in 250 ml conical retort and filled up with 100 ml of 1 % ammonium carbonate solution. The suspension was shaken manually for about 5 minutes and stored for 24 hours. During this time it was shaken every 6 hours. Then, the suspension was filtered through a filter paper. The filtrate was analysed for potassium (K) by flame-photometry. For the phosphorus (P) analysis, the filtrate was decolourised by adding dilute sulphuric acid and 0.5n $KMnO_4$ solution. The mixture was then boiled for 2 minutes. After adding 1 ml of 10 % glucose, the solution was cooled and neutralised with 10 % Na_2CO_3 solution in the presence of an indicator. To 50 ml of colourless mixture, 2 ml of molybdenum reagent solution and 0.5 ml stannous chloride were added. After 5 minutes phosphorus was analysed colorimetrically.

Easy hydrolysed nitrogen (e.g. amino acids, amides, easy hydrolysed proteins) was analysed by the Turin and Kononova method after the treatment of the soil with cold 0.5n sulphuric acid (Radov et al., 1971). The soil sample (20 g) was suspended with 100 ml H_2SO_4. After 16 hours the suspension was filtrated. To the filtrate 0.1 g Fe and 0.8 g Zn were added and then heated until 100°C. After cooling, 5 ml H_2SO_4 was added to the solution and the solution was evaporated until dark colour vapours of SO_2 appear. To the remaining solution 2.5 ml $K_2Cr_2O_7$ (10%) was added and boiled until the solution was turn in green. The cooled solution was placed on a digestion-heating block and then 20 ml NaOH (50%) was added. During 1 hour the solution was digested. The receiver for digested ammonia was a glass of 300 ml containing 15 ml of 0.02n H_2SO_4 and 5 drops red kongo indicator. The available nitrogen is afterwards estimated assuming that 1 ml of 0.02n H_2SO_4 corresponded to 0.28 mg nitrogen.

Amorphous iron was determined by the Vorobeva method (Vorobeva, 1998). Soil samples (0.5 g) were extracted by 25 ml Tamma solution ($H_2C_2O_4*2H_2O$ + $(NH_4)_2C_2O_4*H_2O$; pH 3) and then shaken for 1 hour and centrifuged. Liquids above sediments were poured in 50 ml glasses and sediments were again extracted by 25 ml Tamma solution and the same procedure was applied. Finally, liquids were mixed and analysed by atomic absorption spectrometry (AAS) in an acetylene flame air at 248.4 nm for the presence of iron.

Total humus: The organic matter is oxidized with a mixture of 0.4n $K_2Cr_2O_7$ and H_2SO_4 (1:1, vv). Unused $K_2Cr_2O_7$ is back-titrated with Mora salt ($FeSO_4$). The dilution heat of concentrated $K_2Cr_2O_7$ and H_2SO_4 is the sole source of heat. Because no external source of heat is applied, the method provides only an estimate of readily oxidizable organic carbon and is used as a measure of total organic C. Soil organic matter is estimated assuming that organic matter contains 58 % carbon (Arinushkina, 1980).

Soil microbial biomass and respiration were measured based on infrared gas analysis (Marten et al., 1995). Before biological analysis, soils were incubated for 15 days at 20° C. The method, based on the initial respiratory response of microbial populations to amendment with an excess of a carbon and energy source, was quantified using an expanded version of Jenkinson's technique.

The composition of humus was determined by the Turin and Ponomareva-Plotnikova method modified by Nikitina (Orlov et al., 1981). The humic acid fraction and the fulvic acid fraction were analysed. The soil sample (5 g) was suspended with 200 ml of 0.1n NaOH (alkali suspension) and another soil sample (5 g) with 200 ml of 0.1n H_2SO_4 (acid suspension).

<u>Step 1</u>: After 24 hours, to the <u>alkali suspension</u> 50 ml Na_2SO_4 was added and the suspension was filtrated. From the filtrate two aliquots (10 ml) were taken. One aliquot was evaporated and the total carbon of the alkali suspension was determined by the Turin method. To the second aliquot

10 ml of 0.1n H_2SO_4 was added. After keeping the aliquot for 10 min in an oven at 120-130°C, it was filtrated. The sediment on the filter was washed with acid to remove remains of fulvic acids. Then, the sediment was dissolved by hot 0.1n NaOH. From this solution, the carbon of humic substances (HA1) was analysed by the Turin method. The carbon of fulvic acids was calculated as the difference between total carbon of alkali suspension and carbon of humic substances (HA1). The acid suspension was filtrated and the filtrate was washed with 0.1n H_2SO_4 and finally analysed for carbon by the Turin method (FA1a). The FA1 fraction was calculated as the difference between total carbon of alkali suspension, HA1 and FA1a.

Step 2: From the filtrate of alkali suspension one aliquot (10 ml) was taken, mixed with 10 ml of 0.1n H_2SO_4 and kept for 10 min in the oven (120-130°C). After filtration, the sediment on the filter was washed with 1-2 % Na_2SO_4. From the filtrate, the carbon of humic substances was analysed by the Turin method. The carbon of fulvic acids was calculated as the difference between total carbon of alkali suspension and carbon of humic substances. The HA2 and FA2 fractions were calculated as follows:

HA2 = carbon of humic substances (step 2) - HA1;

FA2 = carbon of fulvic acids + FA1a - carbon of fulvic acids (step 1).

Step 3: The sediment from the filter (from step 2) was washed off with 250 ml of 0.02n NaOH and the resulted suspension was placed on a water-bath for 6 hours. Afterwards, the same operations as in step 2 were carried out for the suspension. The carbon of humic substances (HA3) was obtained by the Turin method. The fraction FA3 was calculated as the difference between total carbon of alkali suspension (step 1), HA3 and FA1a.

In the end, humin (or the non-hydrolysed remain) was calculated as the difference between total humus and all investigated fractions.

2.5 Hydrological properties of soil

All analytical methods were carried out on air-dried and sieved soil materials (< 2mm). For defining the aggregate composition, soil samples were taken as monoliths 40*40*40 cm. Soil hydrological properties were determined at the Forest Institute, Bishkek, Kyrgyzstan. The methods employed are summarised in table 2.7.

Tab. 2.7: Methods for the determination of soil hydrological properties

Parameter	**Method**
Texture of soil	Kachinskii pipette method (Plusnin et al., 1974)
Aggregate composition	Savinov method (Plusnin et al., 1974)
Specific weight	pycnometrically (Plusnin et al., 1974)
Porosity of soil	calculated from data of specific weight and bulk density (Plusnin et al., 1974)

Soil texture was determined according to the Kachniskii pipette method (Plusnin et al., 1974). The soil was separated in fractions based on particle diameters and falling speeds (Stocks formula).

The aggregate composition of soil and soil structure stability (dry and wet sieving) were analysed from monoliths, which were taken as “non-disturbed” structures from each horizon (Plusnin et al., 1974). The soil sample (1 kg) was sifted through a series of sieves (diameters: 10; 5; 3; 2; 1; 0.5 and 0.25 mm). Aggregates were weighted from each sieve and their percentage of the total was calculated. For analysing the soil structure stability, 50 g of sieve fraction sample was taken from each sieve. Each sample was then placed in 1 litre cylinder. The cylinder was filled with water and left for 10 minutes. Afterwards, the cylinder was covered and turned up and down 10 times. Then, the sample was overturn in a special water pool and sieved on a series of sieves (diameters: 3; 2; 1; 0.5 and 0.25 mm). Finally, the soil mass on sieves was dried and weighted. The obtained amount of aggregates on each sieve was multiplied by factor 2, obtaining therefore the percentage of soil aggregate stability.

The specific weight (particle density) was measured pycnometrically (Plusnin et al., 1974). A pycnometer with a capacity of 100 ml was filled up by distilled water of known temperature and was weighted. Afterwards, approximately half of the water was removed from the pycnometer and 10 g of soil sample was added. The suspension was boiled for 30 minutes in order to remove the air from the soil. After cooling till known temperature, the pycnometer was filled with water and weighted.

The p*orosity* of soil was calculated from data of specific weight and bulk density (Plusnin et al., 1974).

2.6 Statistical analysis

For statistical analysis the SPSS software package version 10 was employed (SPSS, 1999). In the present work, the GLM procedure was employed to assess the influence of birch, fir, pine and larch trees on individual parameters. The differences between means were tested using Tukey's multiply test and t-test (LSD) at the 5% significance level.

3 Results

3.1 Composition of forest litter

The forest litter is generally formed from forest falling materials, but when moss or grassland is progressing under the canopies the forest litter includes them also.

The period of forest litter formation depends on the plantation type. In larch and birch plantations the falling material is falling in the autumn period, whereas in fir and pine plantations the time of falling material encompasses the autumn-winter period.

3.1.1 Thickness of forest litter

The thickness of forest litter under investigated plantations is illustrated in figure 3.1. Under the birch crowns, the forest litter was accumulated up to 1 cm, whereas between the crowns it was completely mineralised (Fig. 3.1). The forest litter under the larch plantation was accumulated in a thick layer of 2-4 cm shared between two horizons, namely L (litter) and F (fermentation) (Fig. 3.1).

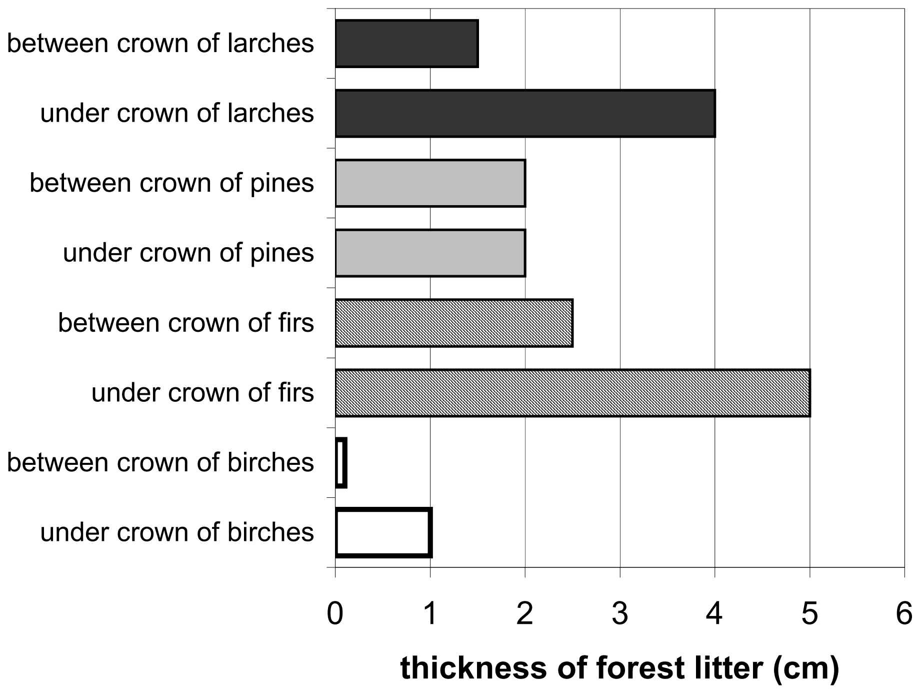


Fig. 3.1: Thickness (cm) of forest litter between and under crowns in birch, fir, pine and larch plantations in the Jylandy boundary (2000)

The fir litter was also clearly shared in two horizons, L (litter) and F (fermentation), and was basically accumulated near tree trunk zones in a 5 cm layer, whereas in the remaining parts of the soil surface the thickness of the forest litter was 2.5 cm less (Fig. 3.1). Under the pine plantation, a 1-2 cm forest litter was formed uniformly on the investigated site (Fig. 3.1). The low thickness of the pine litter indicates higher decomposition processes under the pine plantation compared to coniferous plantations (Fig. 3.1).

3.1.2 Amount of forest litter

In the investigated plantations a considerable amount of forest litter was observed (Fig. 3.2). The analysis of variance showed significant differences ($p < 0.01$) between plantations regarding the amount of forest litter. The largest amount of forest litter was observed in the pine plantation and was approximately three times higher than in the birch plantation, and almost two times higher compared to fir and larch plantations (Fig. 3.2).

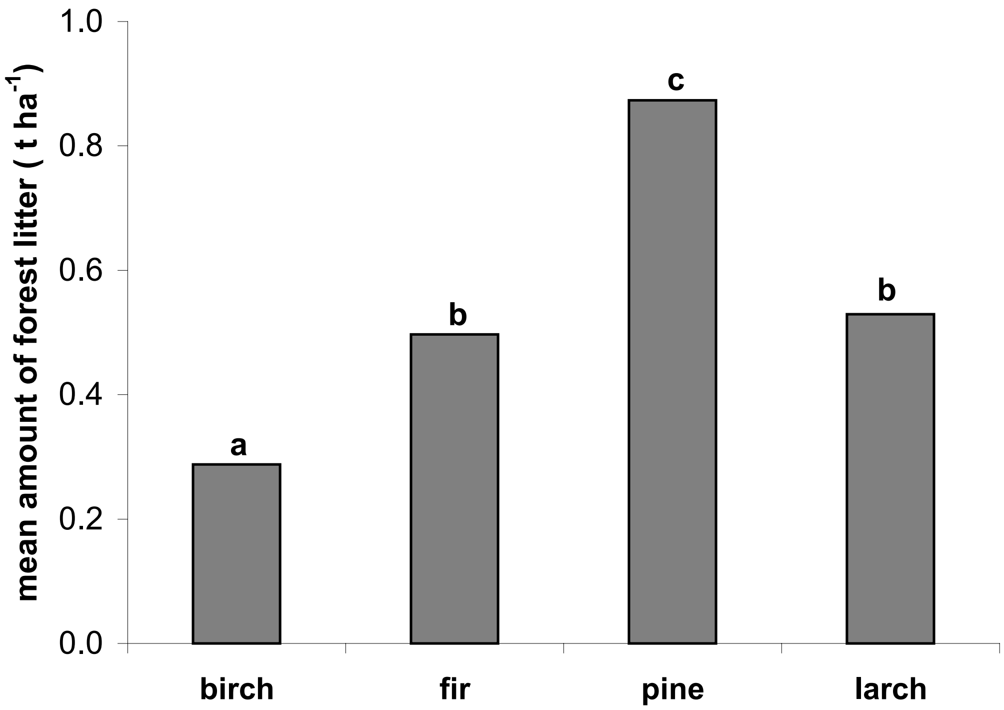


Fig. 3.2: Mean amount of forest litter (t ha^{-1}) in birch, fir, pine and larch plantations in the Jylandy boundary (2000) (different letters denote significant differences between tree plantations by the Tukey test)

3.1.3 Fractional composition of forest litter

The fractional forest litter composition varied depending on the constitution of trees, the progression of floor growth, age, sanitation state, density of trees and other factors. The fractional composition of forest litter for each plantation is shown in table 3.1. The results showed that the principal constituents of the fir litter were needles (31.5 %), of the pine litter cones (52.8 %), of the larch litter branches (30.5 %) and twigs (30.8 %) and of the birch litter branches (42.2 %) and leaves (31.0 %) (Tab. 3.1). The high amount of the litter found under the pine plantation might be due to the heavy cone fraction (Fig. 3.2 and Tab. 3.1). The highest thickness of the fir litter might be explained by the dense canopy cover and the presence of the moss fraction (Fig. 3.1 and Tab. 3.1).

Tab. 3.1: Fractional composition of forest litter (%) in birch, fir, pine and larch plantations in the Jylandy boundary (2000)

Plantations	**needles**	**cones**	**twigs**	**branches**	**moss**	**leaves**	**bark[1]**	**scales[2]**	**decay[3]**	**grass**
	%									
birch	-	-	17.9	42.2	-	31.0	-	-	-	8.9
fir	31.5	5.4	17.2	19.3	7.7	-	3.1	9.6	2.5	3.7
pine	14.9	52.8	6.9	5.8	-	-	12.6	-	-	7.0
larch	12.9	12.6	30.8	30.5	-	-	13.2	-	-	-

note: [1]tree protective out layer; [2]attached to a centre stalk of cones; [3]dust of rotten wood

From the above results it can be concluded that under the investigated plantations the thickness and the amount of forest litter depend on the tree species. Results from the composition of forest litter revealed that coniferous pine and larch needles were decomposed with high velocity. Contrary, the fir needles were decomposed with low velocity that might be due to the presence of the moss fraction. The highest percentage of grass remained in the deciduous birch litter accelerated the decomposition processes, which lead to the complete mineralisation of the birch litter between crowns.

3.2 Chemical composition of forest litter

3.2.1 Acidity of forest litter

The acidity of forest litter collected from the investigated plantations is summarised in figure 3.3. The analysis of variance showed significant differences ($p < 0.01$) between plantations with respect to the acidity of forest litter (Fig. 3.3). Forest litter in pine and larch plantations were moderately acid (pH < 6) and significant differences were found between these plantations, whereas in birch and fir plantations the acidity was slightly acid (approximately pH = 6.5) and no consistently significant differences were revealed (Fig. 3.3).

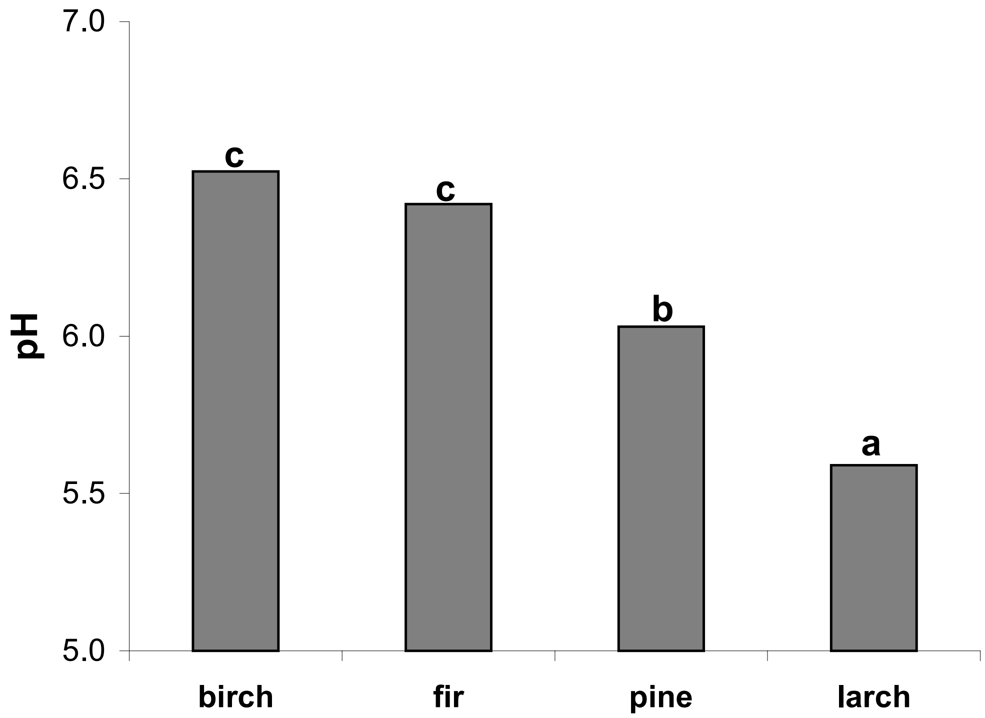


Fig. 3.3: Acidity of birch, fir, pine and larch litter in the Jylandy boundary (2000) (different letters denote significant differences between tree plantations by the Tukey-test)

Statistical analysis revealed no significant differences in the acidity of forest litter under and between crowns in birch and fir plantations (Fig. 3.4). In fir and birch plantations, grown on 10-15° slopes, the pH of forest litter was approximately 6.5 and 6.6 under and between crowns, respectively (Fig. 3.4). On the other hand, in the pine plantation the acidity of forest litter was approximately 6.0 under crowns and 6.4 between crowns, whereas in the larch plantation the corresponding values were 5.6 and 6.0. Pine and larch plantations were grown on higher slopes (30-35°). It can be therefore noticed that the steepness of slopes, i.e. the redistribution of forest litter under gravity, influences the acidity of forest litter between and under crowns. With increasing the steepness significant differences were found regarding the acidity of forest litter between and under crowns (Fig. 3.4).

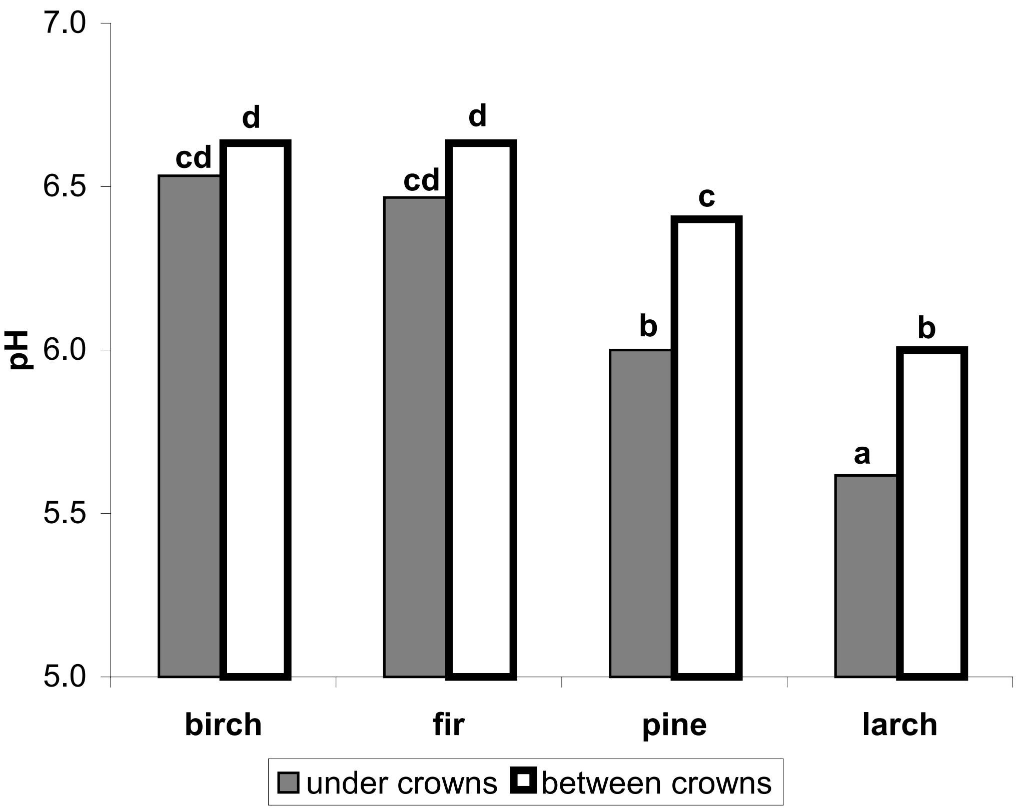


Fig 3.4: Acidity of forest litter between and under crowns in birch, fir, pine and larch plantations in the Jylandy boundary (2000) (different letters denote significant differences under and between crowns by the Tukey-test).

3.2.2 Chemical composition of forest litter

The content of nutrients in the dry matter of forest litter found by all three methods (see subchapter 2.3.4) is summarised in table 3.2.

Tab. 3.2: Content of macro and micronutrients in birch, fir, pine and larch litter in the Jylandy boundary – relating to dry matter (2000)

Macronutrients	**Birch**	**Fir**	**Pine**	**Larch**
	g kg^{-1}			
N	39.0	35.0	42.0	48.0
P	1.3	1.3	0.7	0.9
S	1.1	1.7	1.4	1.5
K	2.3	3.1	6.3	1.5
Ca	18.8	19.9	17.6	14.8
Mg	4.3	2.7	2.3	5.5
Micronutrients	**mg kg^{-1}**			
Si	22,080	23,430	32,850	10,750
Fe	10,735	4,640	5,203	13,547
Al	9,302	4,218	4,180	11,718
Na	1,000	1,100	1,600	400
Ti	336	352	480	130
Zn	120	105	61	56
B	32	41	31	44
Mn	359	204	256	521
Cu	12	9	5	15

note: K, Si, Na and Ti recalculated from the ash content; N analysed by Kjeldahl method; P, Ca, Mg, S, Fe, Al, Zn, B, Mn and Cu by aqua regia digestion.

Calcium carbonate ($CaCO_3$) is known as a compound, which slows down the podzolic processes. A considerable amount of calcium (Ca) was found in the fir litter, followed by birch, pine and larch litter (Tab. 3.2). The largest amount of nitrogen (N) was observed in the larch litter (48 g kg^{-1}) and the smallest in the fir litter (35 g kg^{-1}). A high amount of sulphur (S) (1.7 g

kg^{-1}) was also found in the fir litter, whereas in birch and pine litter the content of this element was low (Tab. 3.2). The phosphorus (P) content was the equal (1.3 g kg^{-1}) in birch and fir litter, followed by larch (0.9 g kg^{-1}) and pine litter (0.7 g kg^{-1}) (Tab. 3.2). The highest amount (6.3 g kg^{-1}) of potassium (K) was found in the pine litter and the lowest K content (1.5 g kg^{-1}) was noticed in the larch litter (Tab. 3.2). The magnesium (Mg) content was high in the larch litter (5.5 g kg^{-1}) followed by birch (4.3 g kg^{-1}), fir (2.7 g kg^{-1}) and pine (2.3 g kg^{-1}) litter (Tab. 3.2).

Elements as iron (Fe) and aluminium (Al) are known as indicators of podzolic processes. The highest value of Fe and Al was noticed in birch and larch litter, whereas in fir and pine litter it was almost twice less (Tab. 3.2). The silicon (Si) content was 32850 mg kg^{-1}, 23430 mg kg^{-1}, 22080 mg kg^{-1} and 10750 mg kg^{-1} in pine, fir, birch and larch litter, respectively (Tab. 3.2). The content of titanium (Ti) and zinc (Zn) was found in the same amount in birch and fir litter (Tab. 3.2). Comparing the copper (Cu) and manganese (Mn) content, it can be seen that in fir and pine litter they were found at lower levels (Tab. 3.2). The highest amount of sodium (Na) was noticed in pine and fir plantations followed by birch and larch plantations. The boron (B) content was approximately the same in all forest litter (Tab. 3.2).

Results from the acidity of forest litter revealed differences between the investigated plantations. Additionally, with increasing the steepness under pine and larch plantations significant differences were found regarding the acidity of forest litter between and under crowns. Nevertheless, under birch and fir plantation grown on slopes with low steepness, the variability of forest litter acidity between and under crowns was not consistently significant. Results from the chemical analysis of forest litter indicated that all investigated forest litter were rich in mineral nutrients.

3.3 Changes in the vegetative cover under the influence of trees

One of the main factors influencing the soil formation process is the vegetation. Vegetation and soil together create a homogenous system. Changes of the vegetation influence on one hand soil properties and on the other hand soil conditions (e.g. moisture, aeration, pH conditions) affect the type of vegetation.

The floristical diversity under the investigated plantations and control glades is summarised in table 3.3. Comparing the floristic diversity between plantations and control glades, it is possible to assume changes in grasslands under the influence of trees during 50 years (Tab. 3.3).

Tab. 3.3: Floristic composition (Drude scale) under birch, fir, pine and larch plantations and on the neighbouring control glades in the Jylandy boundary (2002)

Species	Birch	Glade	Fir	Glade	Pine	Glade	Larch	Glade
Gramineae								
1. Brachypodium pinnatum		Sp2		Cop1	Sp	Sp		
2. Dactylis glomerata	Sol	Sp3		SpSol	SpSol	SpSol		Sp2
3. Elymus caninus		Sol						
4. Millium effusum	Sp	Sp2	Sol	Sol	SpSol	SpSol	Sp2	Sp2
5. Phragmites communis				Un				
6. Phleum phleodis				SpSol				
7. Poa nemoralis	Sp			Sp2				
Cyperacea								
8. Carex atterrima		SpSol		Sp2				
Fabaceae								
9. Lathyrus gmelini	Sol	SpSol		Sp	SpSol	SpSol	SpSol	SpSol
10. Lathyrus pratensis	Sol			Sp				Sp
11. Trifolium pratense	SpSol			Sol				
12. Trifolium repense	SpSol			Sol				
13. Vicia cracca	SpSol	SpSol		SpSol	SpSol	SpSol		Sol
Mixtaherbosa								
14. Aconitum septentrionale	Sol	Sp2	Un	SpSol		SpSol		Sp2
15. Aegopodium alpestre	Sp2	Sp	Sp	SpSol	Sp			
16. Alfredia acantolepis		SpSol		Sp	SpSol	SpSol	SpSol	
17. Anthriscus sylvestris	Sol	Sol		SpSol	SpSol	SpSol		
18. Artemisia vulgaris	Sol			SpSol		SpSol		
19. Arctium leucospermum	Sol							
20. Anemone protracta		SpSol					Sol	
21. Alchimilla atropilosa		Sp						
22. Arctium lasiocarpa								SpSol
23. Allium sp.					Sol			
24. Aqulegia karelini		SpSol		Sol	SpSol	SpSol		
25. Campanula glomerata	SpSol	SpSol		SpSol		Sol		
26. Cardamine impatiens							SpSol	
27. Cerastium dauricum		SpSol		Sp		SpSol	SpSol	SpSol
28. Codonopsis clematidea	SpSol	Sp		SpSol		SpSol	Sp	SpSol
29. Cicerbita tianchanika	Sp				Sp2	Sp2	Cop1Sp	Sp
30. Crepis sibirica	Sol	Sp		Sp	Sp	Sp		
31. Euphrobia alatavica		Sol		Sol				
32. Galium septrentrionale		SpSol		Sp		SpSol		
33. Geranium collinum		Sp		SpSol	Sp			
34. Geranium transversale	Sol				SpSol	SpSol	SpSol	
35. Geum urbanum	SpSol	SpSol		SpSol	SpSol	SpSol	Sp	Sp
36. Goodiera repens			Sol					

Tab. 3.3 continued

Species	Birch	Glade	Fir	Glade	Pine	Glade	Larch	Glade
37. Heracleum dissectum	Sp		Sol	Un	Sp		Sp	Sp
38. Hieraciym sp		Sol						
39. Hypericum perforatum					Sol	Sol		
40. Impatiens parviflora					SpSol		Sp	
41. Lamium album		SpSol		SpSol		SpSol		Sp
42. Ligularia knoringiana	SpSol			Sp	Sol			
43. Melilotus officinalis	Sol							
44. Nepeta pannonica				Sp				
45. Origanum vulgare		SpSol		SpSol	SpSol			
46. Polemonium turkestanica		Sol		SpSol				
47. Polygonatum roseum	Sol		Sol		SpSol			
48. Phlomis oreophila		SpSol						
49. Ranunculus polyanthemus				Sol				
50. Ribes saxatile						Sol		
51. Rumex acetosa		Sol		SpSol				
52. Rumex paulsenianus		Sol						
53. Silene vulgaris		SpSol		SpSol	SpSol			Sol
54. Thalictrum minus	SpSol	SpSol		SpSol	SpSol	Sol		SpSol
55. Trollius altaicus		Sol		SpSol				
56. Urtica dioica	Sp2		SpSol	SpSol	Sp	Sp	Sp2	Sp2
57. Valeriana turkestanica				Sol-un				

From a total of 32 species (i.e. *Gramineae*, *Cyperacea*, *Fabaceae* and *Mixtaherbosa*) found on the control glade near the birch plantation only 12 species were observed under birch trees, whereas 13 species were substituted by other species and 7 species disappeared (Tab. 3.3). From 4 *Gramineae* species found on the control glade, 2 remained in the birch plantation and *Poa nemoralis* (Drude scale: *Sp*- see photo 3) emerged. On the control glade, 2 *Fabaceae* species were recognised and they were also described under birch trees (Tab. 3.3). Additionally, in the birch plantation 3 *Fabaceae* species were observed, namely: *Lathyrus pratensis* (Drude scale: *Sol*); *Trifolium pratense* (Drude scale: *Sp Sol)* and *Trifolium repens* (Drude scale: *Sp*- see photo 3). From 25 *Mixtaherbosa* species found on the control glade, 7 former species remained, whereas 9 new species appeared in the birch plantation (i.e. *Artemisia vulgaris; Arctium leucospermum; Cicerbita tianchanika; Geranium transversale; Heracleum dissectum; Ligularia knoringiana; Mililotus officinalis; Polygonatum roseum; Urtica dioica*).


Photo 3: *Poa nemoralis* (left; Drude scale: *Sp*) and *Trifolium repens* (right; Drude scale: *Sp*) in the Jylandy boundary (photos provided by the Forest Institute, Kyrgyzstan)

On the other hand, the vegetation on the control glade near the fir plantation consisted of 39 species (i.e. *Gramineae*, *Cyperacea*, *Fabaceae* and *Mixtaherbosa*). Under the fir plantation, 5 species from *Gramineae* and *Mixtaherbosa* remained (Tab. 3.3) and 2 *Mixtaherbosa* species appeared (*Goodiera repens* and *Polygonatum roseum*, see photo 4).


Photo 4: *Goodiera repens* (left; Drude scale: *Sol*) and *Polygonatum roseum* (right; Drude scale: *Sol*) in the Jylandy boundary (photos provided by the Forest Institute, Kyrgyzstan)

The grass glade near the pine plantation consisted of 23 species (i.e. *Gramineae, Fabaceae* and *Mixtaherbosa*) (Tab. 3.3). During 50 years they were substituted in the pine plantation with other 9 species, whereas 15 species remained (Tab. 3.3). The same *Gramineae* and *Fabaceae* species were found in the pine plantation as on the neighbouring glade, whereas from *Mixtaherbosa* species were observed only 10 in the pine plantation and new 9 species appeared (i.e. *Aegopodium alpestre; Anthriscus sylvestris; Allium sp; Geranium collinum* - photo 5; *Goodiera repens* - photo 4; *Heracleum dissectum* - photo 5; *Impatients parviflora* - photo 6; *Origanum vulgare; Silene vulgaris*).

Photo 5: *Heracleum dissectum* (left; Drude scale: *Sp*) and *Geranium collinum* (right; Drude scale: *Sp*) in the Jylandy boundary (photos provided by the Forest Institute, Kyrgyzstan)

The floristic composition on the control glade near the larch plantation was composed of 16 species (i.e. *Gramineae*, *Fabaceae* and *Mixtaherbosa*). Under the larch plantation, 8 species were left and 5 new species appeared (Tab. 3.3). From the *Gramineae* and *Fabaceae* species on the glade, in the larch plantation remained one from each group. In the same time in the larch plantation, 6 *Mixtaherbosa* species from the control glade were found and 5 new species appeared (i.e. *Alfredia acantolepis; Geranium transversale* - photo 6*; Anemonastrum protactrum; Impatiens parvilflora* - photo 6; *Cardamine impatiens*).

Photo 6: *Geranium transversale* (left; Drude scale: *Sp Sol*) and *Impatiens parviflora* (right; Drude scale: *Sp*) in the Jylandy boundary (photos provided by the Forest Institute, Kyrgyzstan)

From the above results it can be concluded that the biological features of trees (e.g. height of trees, canopy closure) influence the grassy vegetation in all plantations. The birch tree forms a friable crown, which is not shadowing the soil surface and consequently variations between the control glade and the birch plantation were not so different. On the other hand, the dense fir crowns create conditions that detain the sunlight under the canopies and therefore poor floristic composition under the fir plantation was observed. In the pine plantation, open spaces were created between crowns and therefore some variations in the grassy vegetation were noticed. Contrary, under the larch plantation shadow loving vegetation grew.

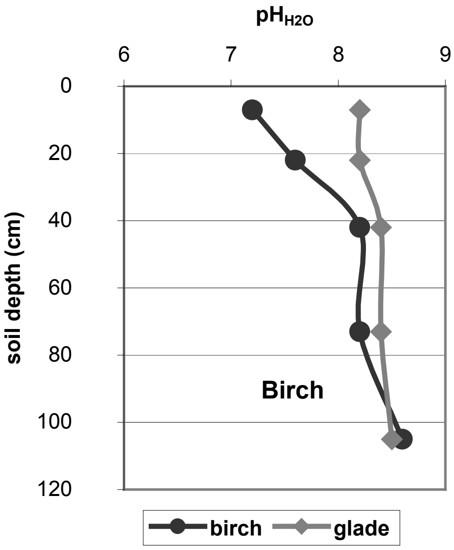
3.4 Chemical composition of soils

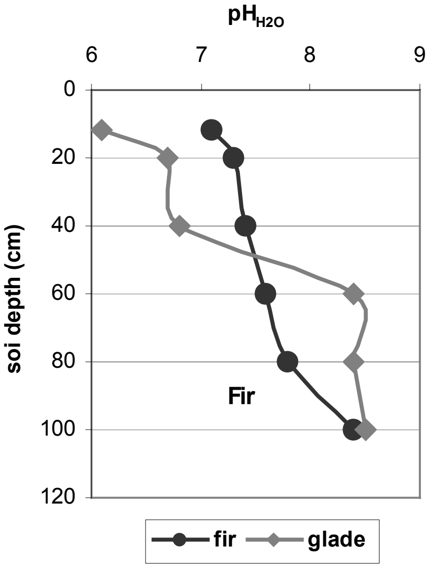
3.4.1 Morphological indices

Essential distinctions in morphological indices appear only under long time of trees growing. In all profiles the thickness of humus horizons was approximately the same compared to the control glades (see Appendix: Fig. A4-A11). The HCl test (or line) of soils for assessing the lime status under larch and birch plantations was identical compared to the control glades. On the other hand, the HCl line dropped down by 20 cm under the pine plantation and by 40 cm under the fir plantation compared to the control glades (see Appendix: Fig. A4-A11). Additionally, data showed that the horizon E (zone of strongest leaching) in soil profiles did not morphologically occur under all investigated plantations.

3.4.2 Soil pH

The acidity of soils under plantations and control glades is illustrated in figures 3.5-3.6. It could be shown that there were differences in the soil acidity between plantations and open areas (glades). The pH under birch, pine and larch plantations decreased in the upper 50 cm of the soil profile compared to the control glades, whereas in the soil under the fir plantation increased (see Fig. 3.5-3.6).





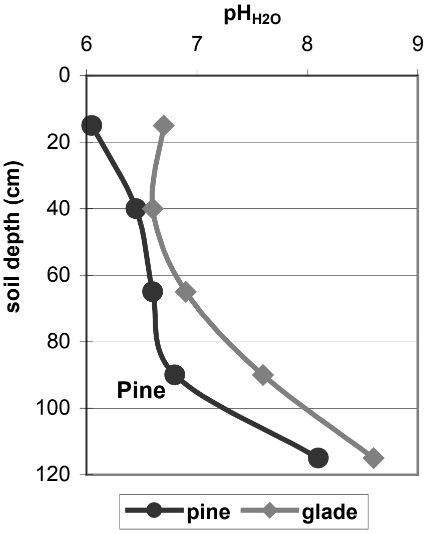
$LSD_{5\%}$ (birch and glade) = 0.163

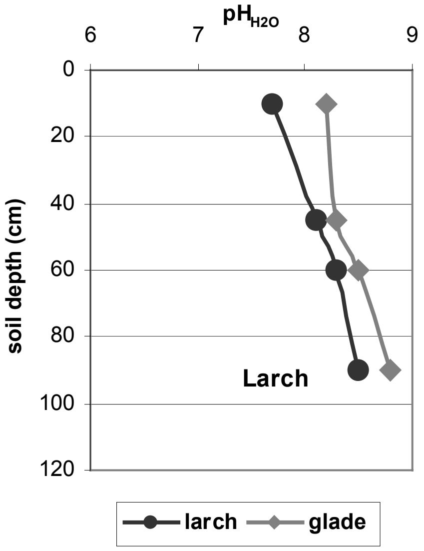
$LSD_{5\%}$ (depth) = 0.257

$LSD_{5\%}$ (fir and glade) = 0.267

$LSD_{5\%}$ (depth) = 0.465

Fig 3.5: Soil $pH_{(water)}$ under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)





LSD$_{5\%}$ (pine and glade) = 0.109
LSD$_{5\%}$ (depth) = 0.172

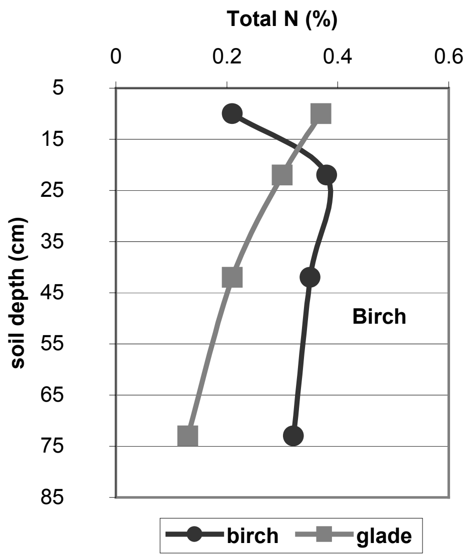
LSD$_{5\%}$ (larch and glade) = 0.071
LSD$_{5\%}$ (depth) = 0.101

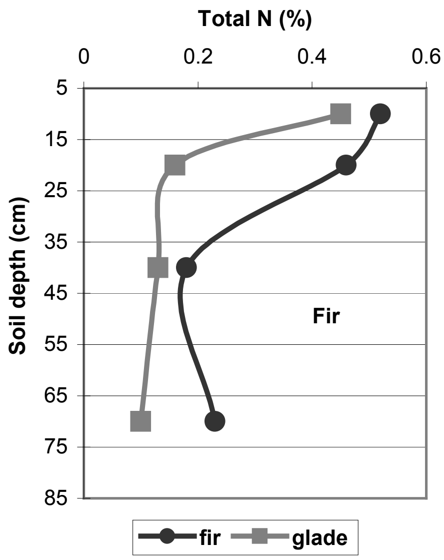
Fig 3.6: Soil pH$_{(water)}$ under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

3.4.3 Macronutrient contents

Macronutrients are essential for plant nutrition in close connection with soil properties such as humus content and acidity. The total soil nitrogen (N) content in the investigated plantations and glades is summarised in figures 3.7-3.8. Soil samples were taken in the summer period when intensive decomposition of forest litter occurs due to high microbiological activity.

As can been seen in figures 3.7-3.8, the content of total N in soils under fir and larch plantations was higher than in the neighbouring glades. Under the birch plantation, the total content of N in the upper layer (10 cm) was low compared to the control glade, but afterwards it increased with the deepness (Fig. 3.7). The total N content in the soil under the pine plantation increased in the upper soil layer compared to the control glade, whereas till 65 cm in the soil profile a decrease was noticed. The content of total N in the soil profile under the pine plantation was uniformly distributed (Fig. 3.8). The distribution of the total N in soil profiles under fir and larch plantations was unevenly. The N content decreased till 45 cm in the soil profiles and then gradually increased till 60 cm (Fig. 3.7-3.8).





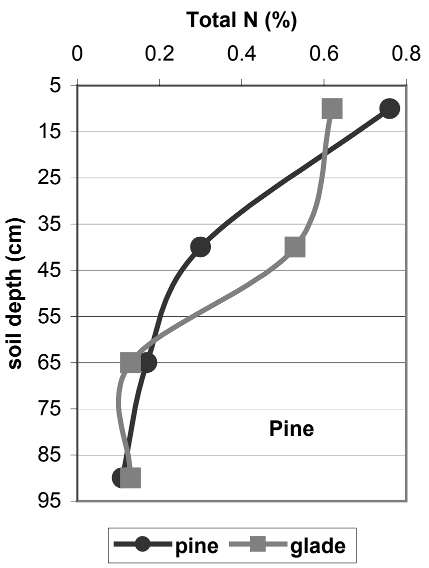
LSD$_{5\%}$ (birch and glade) = 0.066

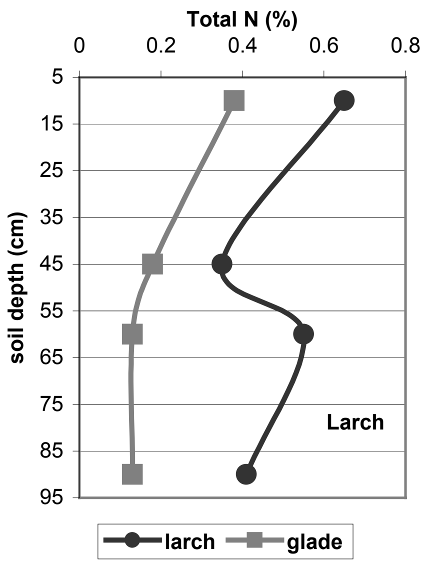
LSD$_{5\%}$ (depth) = 0.093

LSD$_{5\%}$ (fir and glade) = 0.047

LSD$_{5\%}$ (depth) = 0.066

Fig 3.7: Total soil nitrogen content (%) under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)





LSD$_{5\%}$ (pine and glade) = 0.066

LSD$_{5\%}$ (depth) = 0.093

LSD$_{5\%}$ (larch and glade) = 0.047

LSD$_{5\%}$ (depth) = 0.066

Fig 3.8: Total soil nitrogen content (%) under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

The turnover of soil organic matter (SOM) is affected by the C:N ratio and the effective mineralisation time. Decomposing microbes are the most active and efficient when the C:N ratio ranges between 20 and 30. The C:N ratios in soils under all investigated plantations and control glades are illustrated in figures 3.9-3.10.

The C:N ratio in the upper soil layers under fir, pine and larch plantations ranged between 20 and 30 (Fig. 3.9-3.10). Consequently, the C:N ratio was found optimum under these plantations. The high C:N ratio in the upper soil layer under the birch plantation indicates that the decomposition process was decelerated compared to fir, pine and larch plantations (Fig. 3.9). Additionally, data showed that the C:N ratios in the upper soil layers under all investigated plantations were higher compared to the control glades. With increasing the soil depth the ratio became closer, pronounced in the forest planatations (Fig. 3.9-3.10).

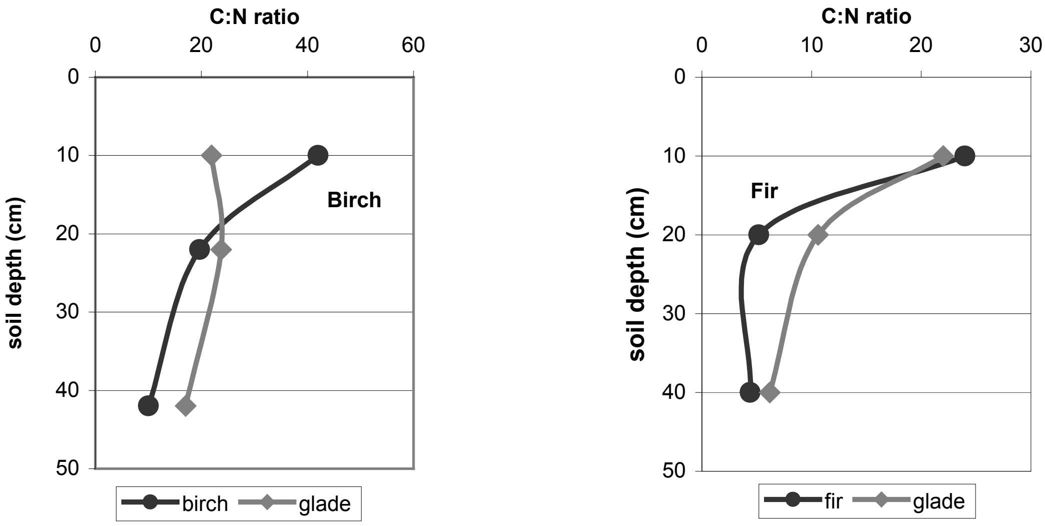


Fig. 3.9: C:N ratio in soils under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)

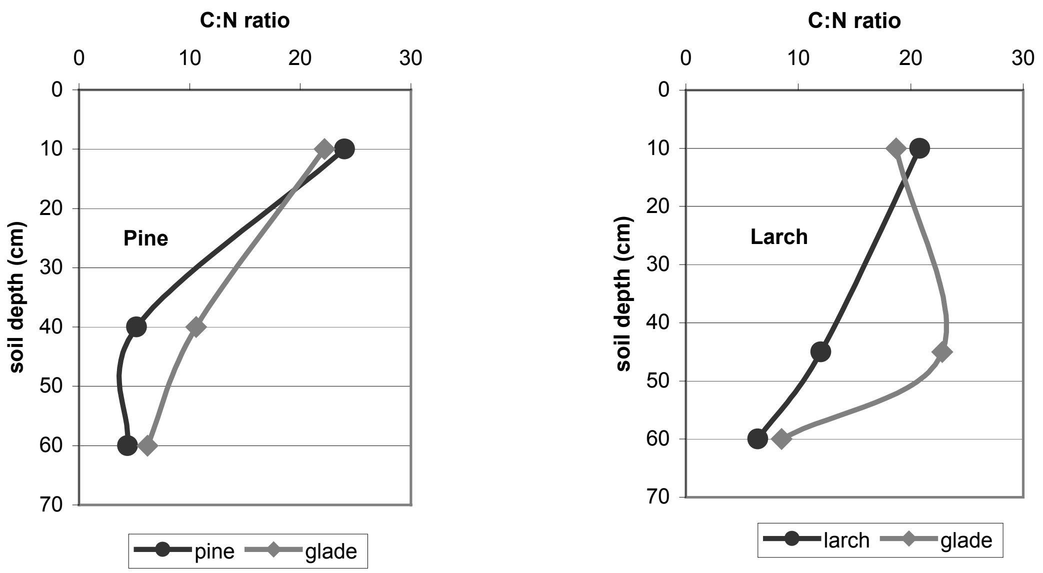


Fig. 3.10: C:N ratio in soils under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

Soil samples collected from the investigated plantations and control glades were analysed for the total content of macronutrients (see Subchapter 2.4.2). The summarised data are shown in table 3.4. The P and S contents were higher in soils under the investigated plantations than in the control glades. The Ca and Mg contents increased under fir, pine and larch plantations compared to the control glades, whereas they decreased in the soil under the birch plantation (Tab. 3.4).

Comparing the macronutrient contents between the plantations, it can be noticed that the highest amount of P (2,910 mg kg^{-1}) was analysed in the soil under the birch plantation and the lowest (1,918 mg kg^{-1}) in the soil under the larch plantation (Tab. 3.4). The contents of Ca (25,953 mg kg^{-1}) and S (2,480 mg kg^{-1}) were the highest in the soil under the pine plantation (Tab. 3.4). Contrary, in soils under fir and larch plantations the smallest total amount of Ca (20,520 mg kg^{-1}) was found. The smallest contents of Mg and S were observed in soils under birch (1,625 mg kg^{-1}) and pine (18,590 mg kg^{-1}) plantations (Tab. 3.4).

Tab. 3.4: Total macronutrient contents (mg kg^{-1}) in soils under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2000)

Trial plots /soil depth (cm)	**P**	**Mg**	**Ca**	**S**
	---mg kg^{-1}---			
Birch /3-13	2,910	21,839	24,292	1,625
Glade /0-10	2,754	22,750	37,647	1,539
Fir /2-12	2,324	21,805	20,537	1,757
Glade /0-10	2,078	20,711	18,978	1,721
Pine /3-13	2,415	19,590	25,953	2,480
Glade /0-10	1,832	19,402	20,813	1,975
Larch /5-15	1,918	21,552	20,500	1,984
Glade /0-10	1,699	20,814	16,933	1,290

The amount of available or mineral N in soils under the investigated plantations and control glades is shown in figures 3.11-3.12. The nitrification processes are more intensive in the upper wet soil layers where the amount of available N in soils under fir, pine and larch plantation was 570 mg kg^{-1}, 840 mg kg^{-1} and 710 mg kg^{-1}, respectively (Fig. 3.11-3.12). In the upper soil layers under fir, pine and larch plantations, the amount of available N was higher than in the control glades. The distribution of available N in the soil profiles followed the same tendency as in case of total nitrogen (see Fig 3.11-3.12 and Fig. 3.7-3.8).

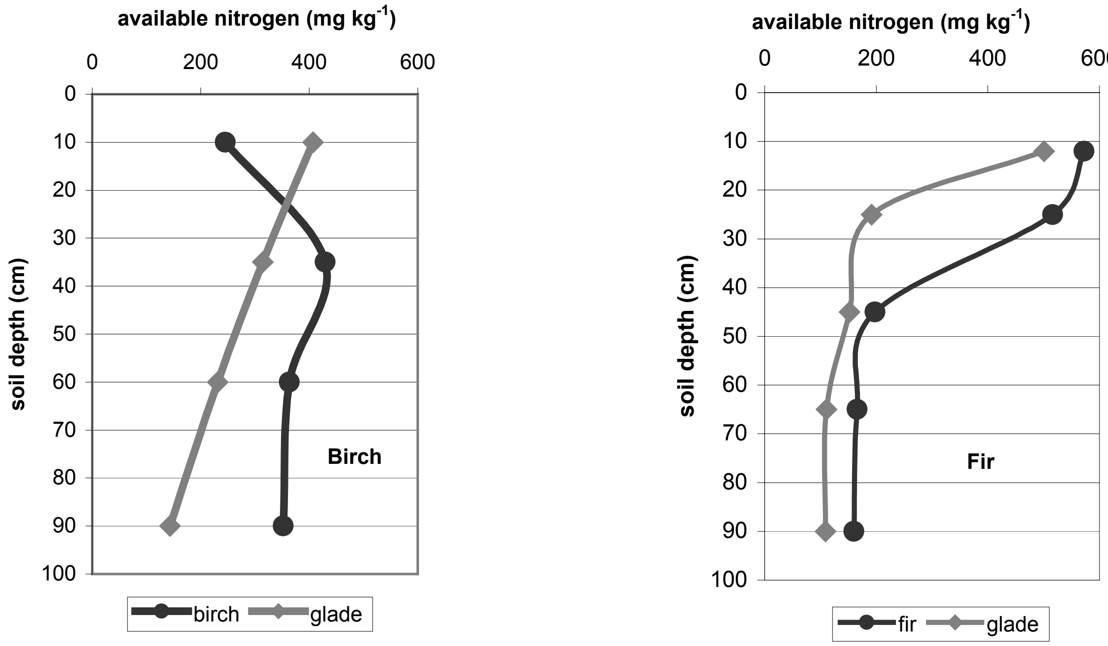


Fig. 3.11: Plant available nitrogen (mg kg^{-1}) under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)

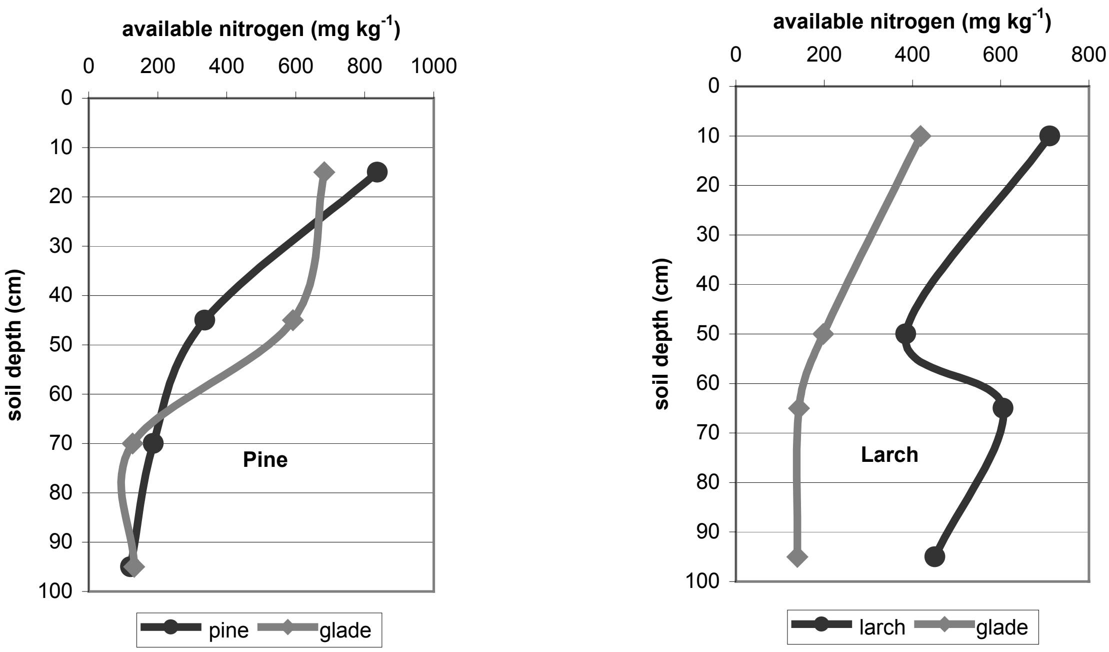


Fig. 3.12: Plant available nitrogen (mg kg^{-1}) under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

The content of available P in soils under all plantations was unequally increased compared to the control glades (Fig. 3.13-3.14). The highest amount of available P in the upper soil layers was found under larch and fir plantations (25 mg kg^{-1}). Under pine and birch plantations a smaller amount of P was determined in the soil (14 mg kg^{-1}) (Fig. 3.13-3.14).

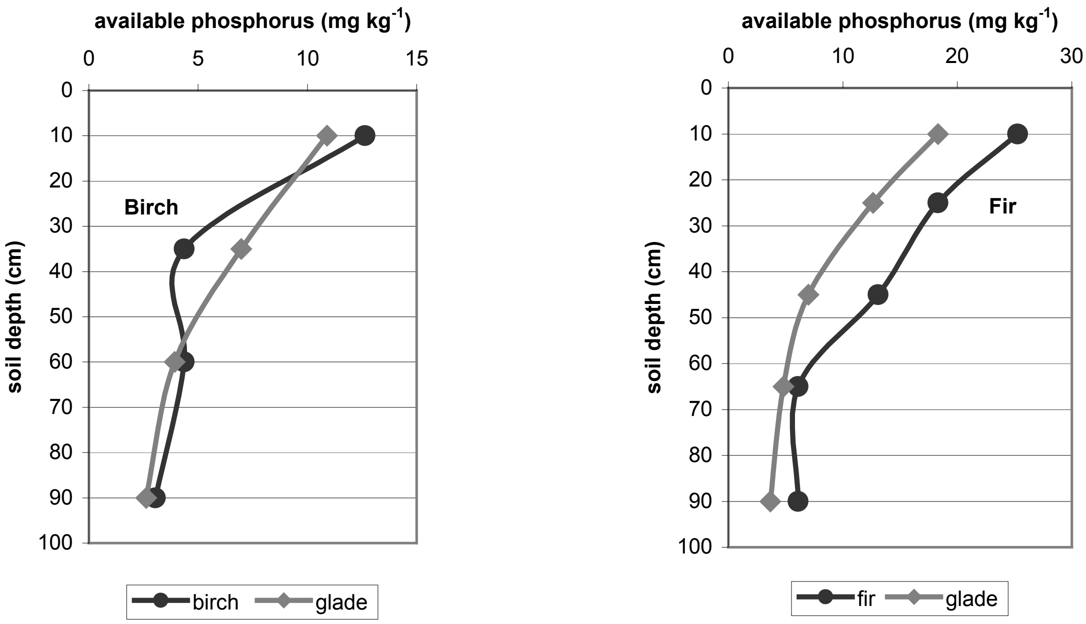


Fig. 3.13: Plant available phosphorus (mg kg^{-1}) under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)

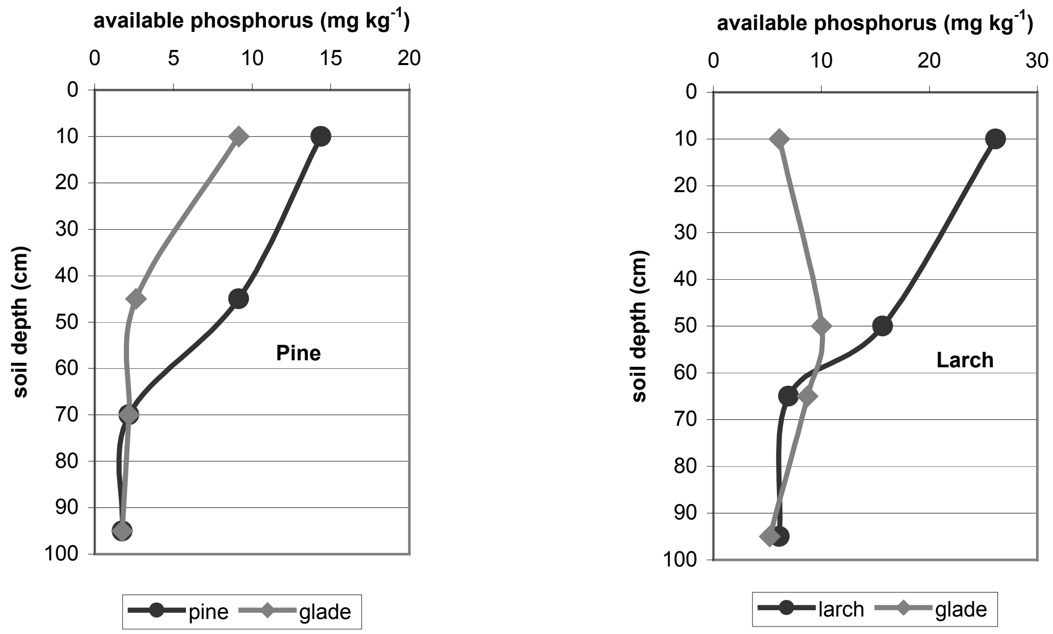


Fig. 3.14: Plant available phosphorus (mg kg^{-1}) under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

Data also showed that the available K in soil upper layers increased under all plantations compared to the control glades (Fig. 3.15-3.16). Nevertheless, under the larch plantation, with increasing the soil depth, a decrease was found compared to the control glade (Fig. 3.16). Comparing the amount of available K in the soil profiles, it can be observed that it was higher in the upper layers than in the lower layers. This phenomenon can be explained by the accumulation of humus substances and by soil conditions, which further mobilise K from minerals (Fig. 3.15-3.16).

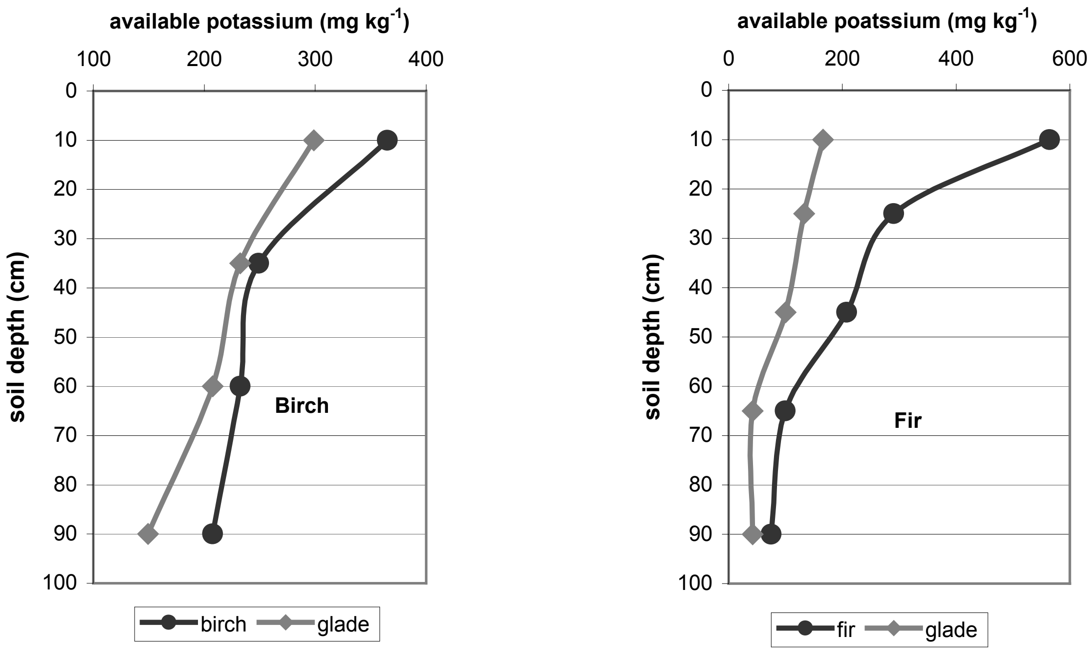


Fig. 3.15: Plant available potassium (mg kg^{-1}) under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)

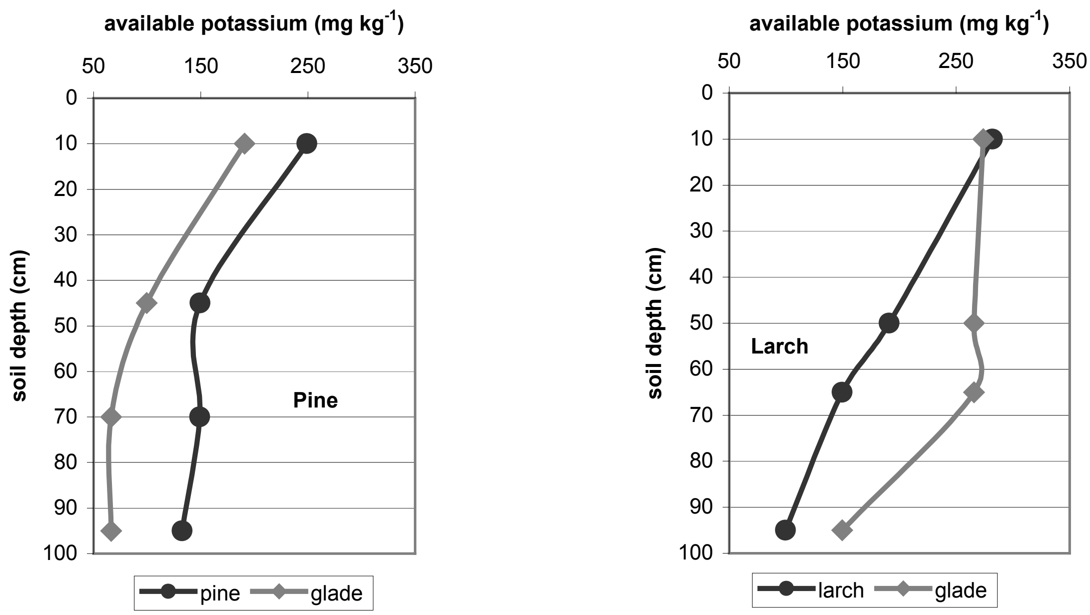


Fig. 3.16: Plant available potassium (mg kg^{-1}) under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

3.4.4 Micronutrient contents

Micronutrients were determined by aqua regia digestion (see Subchapter 2.4.2) and the data are shown in table 3.5. In the soil under the fir plantation all microelements were found in higher levels compared to the control glade (Tab. 3.5). The same tendency was observed in the soil under the pine plantation. The content of Fe and B in the soil under the birch plantation decreased compared to the control, whereas Mn and Zn increased (Tab. 3.5). A disproportional distribution of microelements was observed in the soil under the larch plantation, where the total amount of Fe, Zn and Mn was lower than in the control glade, whereas the B content increased. The data also revealed that in soils under all plantations the total amount of Cu remained almost the same compared to the control glades (Tab. 3.5)

Tab. 3.5: Total micronutrient contents (mg kg^{-1}) in soils under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2000)

Trial plots /soil depth (cm)	**Fe**	**Mn**	**B**	**Zn**	**Cu**
	mg kg^{-1}				
Birch /3-13	57,526	1,624	72	215	59
Glade /0-10	60,515	1,614	75	207	59
Fir /2-12	62,331	1,671	82	175	55
Glade /0-10	53,283	1,526	67	138	47
Pine /3-13	56,492	1,785	82	224	55
Glade /0-10	57,066	1,658	77	188	49
Larch /5-15	60,237	1,683	86	157	52
Glade /0-10	67,200	1,755	76	158	54

Comparing the amount of micronutrients between plantations, it can be seen that B content (72-86 mg kg^{-1}) in soils showed no large variations (Tab. 3.5). The highest amount of Fe was found in soils under the fir plantation followed by larch, birch and pine plantations. The Mn content was highest (1,785 mg kg^{-1}) in the soil under the pine plantation and smallest (1,624 mg kg^{-1}) in the soil under the birch plantation (Tab. 3.5). The Zn content in soils under all investigated plantations ranged between 157-224 mg kg^{-1} (Tab. 3.5).

The content of amorphous Fe in soils under birch, fir, pine and larch plantations and in the control glades was investigated by the Vorobeva method at the Moscow State University (see Subchapter 2.4.2). These results are illustrated in figures 3.17-3.18.

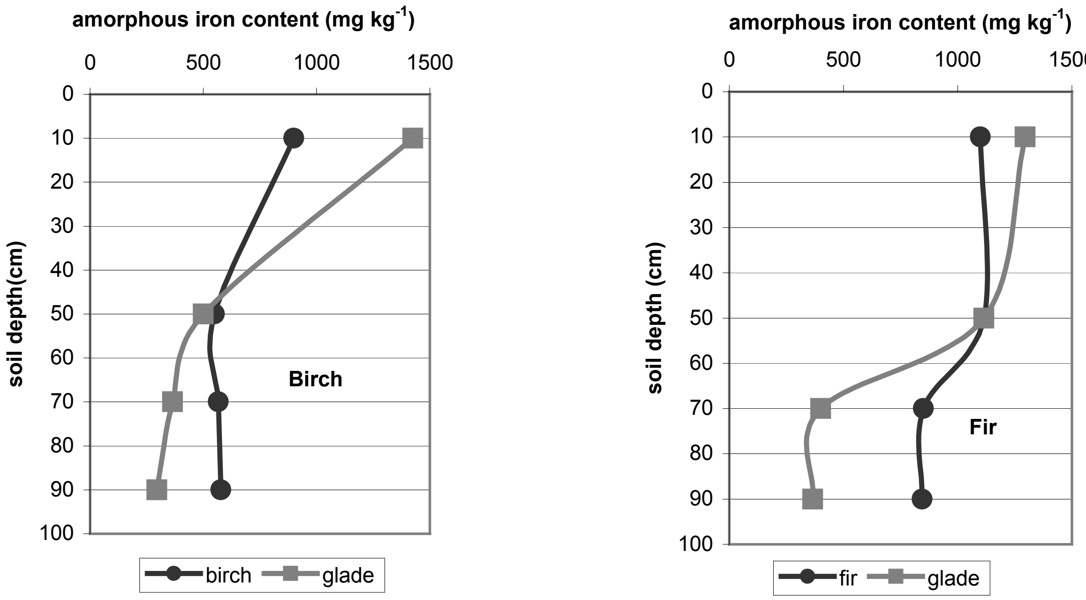


Fig. 3.17: Amorphous iron content (mg kg^{-1}) in soils under birch (left) and fir (right) plantations and in the control glades in the Jylandy boundary (2000)

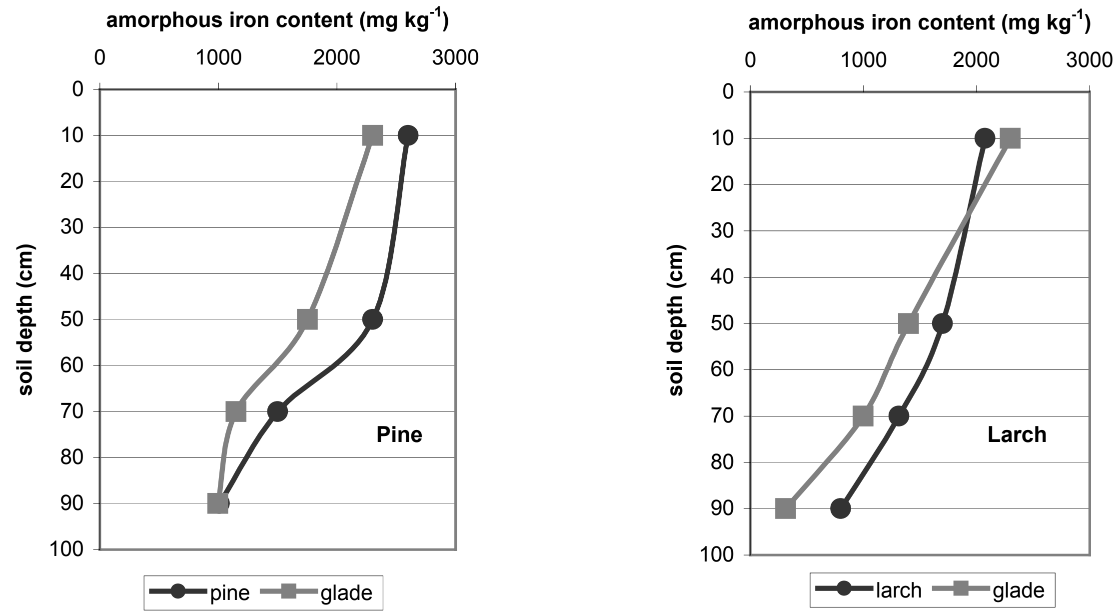


Fig. 3.18: Amorphous iron content (mg kg^{-1}) in soils under pine (left) and larch (right) plantations and in the control glades in the Jylandy boundary (2000)

The content of amorphous Fe in soils under larch, birch and fir plantations decreased in the upper layers compared to the control glades (Fig. 3.17-3.18). Additionally, under these plantations the content of amorphous Fe increased with the depth of soil profiles. In the soil under the pine plantation the amount of amorphous Fe was higher than in the control glade (Fig. 3.18).

Comparing the content of amorphous Fe in soils under the control glades by the Zonn schema (Zonn, 1982), it was revealed that trees were planted on chernozems close to typical chernozems (Fig. 3.17-3.18). The Zonn (1982) schema is describing the amorphous iron content in different soil types of former USSR. A typical chernozem is characterised by a uniformly distribution of all iron forms (except the crystal form) (Zonn, 1982).

The data revealed that the distribution of amorphous Fe in the soil profiles was uniformly under pine and larch plantations (Fig. 3.18). This indicates that under these plantations the podzolic processes did not occur. Generally, the highest amount of amorphous iron in podzol soils is accumulated in AB layers (Zonn, 1982). On the other hand, in the soil under the fir plantation, the iron content was high till the middle of profile and then decreased (Fig. 3.17). Contrary, under the birch plantation the Fe content decreased on 50 cm and afterwards increased with the depth of profile (Fig. 3.17). This might be due to the fact that under birch and fir plantations the short water stagnation influenced the redistribution of amorphous Fe in soils.

3.4.5 Humus composition

Data on quantitative and qualitative humus composition in soils under the investigated plantations and in the control glades are summarised in table 3.6. In soils under all investigated plantations the total amount of humus was higher compared to the control glades. For instance, in the upper soil layers the amount of humus increased by absolutely 18.4 % under the pine plantation compared to the control, whereas under larch, fir and birch plantations increasing contents by 6.4 %, 2.5 % and 0.7 %, respectively were noticed (Tab. 3.6).

Beside differences in the humic acid content found between investigated plantations and control glades, differences were also observed with respect to the spatial distribution of the humus. In the upper soil layers under fir and pine plantations a higher content of humic acids was noticed compared to controls. On the other hand, in soils under larch and birch plantations a reverse pattern was found (Tab. 3.6).

Tab. 3.6: Quantitative and qualitative humus composition in the Jylandy boundary (2000)

Trial plots soil depth (cm)	Total humus	Humic acid (HA) HA1	HA2	HA3	Sum	Fulvic acid (FA) FA1a	FA1	FA2	FA3	Sum	Humin	HA/FA
	%											
Birch												
3-10	8.82	9.0	21.4	17.6	48.2	1.7	4.8	20.1	-	26.8	24.9	1.7
20-30	7.48	21.0	29.8	10.4	61.3	1.8	3.3	13.5	-	18.8	17.3	3.2
40-50	3.50	14.0	1.36	37.0	52.4	4.4	3.4	6.8	-	14.7	27.7	3.5
Glade												
0.5-15	8.12	14.5	43.9	0.9	59.4	3.2	8.8	6.5	-	18.6	19.0	3.1
20-30	7.12	22.2	35.8	1.2	59.3	4.3	17.9	-	-	22.2	17.4	2.6
40-50	3.58	20.6	-	15.8	36.5	7.0	15.5	-	-	22.5	29.4	1.5
Fir												
2-12	12.5	17.6	12.8	28.9	59.3	0.9	4.9	17.4	-	23.3	16.9	2.5
15-25	2.4	8.7	1.0	15.7	25.4	1.0	11.2	16.1	7.6	36.0	31.6	0.7
35-45	0.8	11.3	12	12.3	35.7	1.2	14.8	17.7	15.7	49.5	14.7	0.7
Glade												
0-10	10.0	10.0	14.3	14.3	36.6	0.5	20.9	-	12.3	33.8	24.7	1.1
15-25	1.7	16.2	20.8	3.5	40.6	1.6	8.3	13.0	17.9	40.9	18.4	0.9
35-45	0.8	4.6	29.4	26.2	60.3	1.4	16.3	6.3	6.0	30.4	9.2	1.9
Pine												
3-13	25.9	23.0	28.5	7.9	59.4	1.1	9.8	8.2	-	19.2	21.2	3
35-45	14.4	18.3	24.7	15.5	56.8	1.2	7.9	10.9	-	20.0	23.1	2.9
65-75	6.93	22.3	15.6	27.5	65.5	2.4	9.3	-	-	11.7	22.6	5.5
Glade												
5-15	7.5	10.2	29.7	3.8	43.8	2.0	14.3	-	-	16.3	34.4	2.6
35-45	6.2	15.5	24.2	22.2	61.9	2.3	11.9	-	-	14.2	21.9	4.3
65-75	6.1	5.0	21.4	34.4	60.9	2.1	21.4	-	-	23.5	12.2	2.5
Larch												
4-14	13.5	38.9	6.2	8.8	53.3	3.2	3.2	9.5	8.8	24.2	17.7	2.2
40-50	4.2	4.7	26.9	25.0	56.7	3.3	1.4	4.2	8.2	17.2	25.9	3.3
55-65	3.5	7.8	21.0	23.6	52.5	2.7	1.0	0.3	21.6	25.9	21.1	2.1
Glade												
0-10	7.1	29.6	41.0	-	70.7	3.5	1.7	22.0	-	27.2	1.9	2.5
40-50	4.1	31.4	39.5	-	69.0	2.6	4.2	11.5	-	18.4	12.2	3.8
55-65	1.1	30.0	7.15	-	37.2	8.0	-	18.2	-	26.3	36.4	1.4

Depending on the soil depth, the content of humic acids ranged between 25.4-65.5 % in soils under all plantations and between 36.5-70.7 % in soils under the control glades (Tab. 3.6). Changes in the humic acid content in the soil corresponded with in an increase or a decrease of fulvic acids. The fulvic acid contents varied in soils under the investigated plantations from 11.7 % to 49.5 % and in the control glades from 14.2 % up to 40.9 % (Tab. 3.6). Additionally, the ratios between humic and fulvic acids were also changed. Thus, in soils under the investigated plantations the ratio varied from 0.7 to 5.5 and in the control glades from 0.9 to 4.3 (Tab. 3.6).

In soils under the investigated plantations a fractional distribution of humic acids was also observed. In soils of the control glades near birch and fir plantations, the black humic acids (HA2) were dominated (Tab. 3.6). This indicates that fir and birch plantations were grown on mountain chernozem. The mountain chernozem is characterised by a high humus content, which gradually decreases with the depth of the profile (Mamytov and Bobrov, 1977). It seems therefore that the profile is filled up with humus till the carbonate containing horizon, which prevents the translocation of humus substances in deeper zones of the profile. On the other hand, larch and pine plantations were created on leached mountain chernozem. A leached chernozem is characterised by an increase of humic acids in soil solutions (Ponamoreva and Plotnikova, 1980). In the control glades near pine and larch plantations, the HA:FA ratio increased between 20 and 50 cm of the soil profiles. The ratio between HA and FA varied from 3.8 to 4.3 (Tab. 3.6). The high content of humic acids in the leached chernozems compared to a typical chernozem might be due to the fact that in leached chernozems humic acids are more soluble than in typical chernozems (Ponamoreva and Plotnikova, 1980). In the upper soil layers under fir, pine and larch plantations, the content of brown humic acids (HA1) increased compared to the control glades, whereas under the birch plantation a decrease was noticed (Tab. 3.6). The fraction HA3, which is strongly bound to oxides prevailed under the fir plantation (Tab. 3.6).

The high contents of fulvic acids correspond with the increase of the fractions FA1 and FA2. Simultaneously, in most cases in soils under forest plantations a decrease of fulvic fraction FA1a was found compared to the control glades (Tab. 3.6). The FA1a fraction is very mobile and also known to be an aggressive acid, destroying minerals in soils.

Trees influence the soil humus composition differently. Substances formed by forest litter decomposition were more consolidated in the soil depth till 35 cm. The fractional composition of humus in the soil under the birch plantation was characterised by the dominance of the second humic acid fraction (HA2). The content of fulvic acids in the second fraction (FA2) decreased noticeable with the depth of profiles and composed approximately half of all fulvic acid fractions. The FA1 fraction was found in low amount in the soil under the birch plantation. From the ratio humic acids to fulvic acids, the soil type under the birch plantation may be classified as humat-fulvat type.

The soil under the fir plantation was characterised by the dominance of humic acids in the top layer of the soil profile till 12 cm. The increase of humic acids is reflected primarily in the increase of HA1 and HA3 fractions. However, in the middle part of the soil profile, fulvic acids were dominated above humic acids. In this part of the soil, the FA2 fraction was found at significant level, consisting of more than 50 % of all fulvic acid fractions. Based on the qualitative composition of humus, the soil under the fir plantation may be referred as fulvat-humat type.

Concerning the influence of the pine plantation on the humus composition, it can be seen in table 3.6 that from all fractions the humic acid fraction prevailed. From all humic acid fractions, the fraction HA2 was found in sufficient level. In the middle of the profile, the amount of humic acids was 50-60 %. This was primarily due to a high increase of HA2 fraction (20-27%). Moreover, the second humic acid fraction (HA2) was more consolidated till 40 cm. Usually, the fraction HA2 is bound to Ca in the soil profile. Based on the ratio HA to FA, the soil under the pine plantation may be classified as humat-fulvat type.

In the soil under larch trees, the content of humic and fulvic acids increased from the surface till the depth 40-50 cm. This indicates that leaching processes occurred on this depth. Moreover, from all fulvic acid fractions the third fraction (FA3) was leached to a higher extent. It might be also possible that the humin could be hydrolysed during leaching. It can be seen in table 3.6 that the amount of humin was higher in the soil profile from 20 to 30 cm and afterwards decreased till the soil depth of 40-50 cm. According to the HA:FA ratio, the soil under the larch plantation may be referred as humat-fulvat type.

Results from the soil acidity showed a decrease in the soil pH under pine, larch and birch plantations compared to the control glades, while in the soil profile under the fir plantation an increase was found. It might be due to the fact that the fir litter was rich in Ca and Mg content.

Results from soil macronutrient contents revealed that under coniferous plantations (i.e. larch, pine, fir) an increase of macroelements was found, whereas in the soil under the birch plantation a decrease of the Ca and Mg content occurred. Additionally, the C:N ratio in soils under fir, pine and larch plantations was optimum.

Results from soil micronutrient contents indicated that in soils under fir and pine plantations all micronutrients were found at higher levels than in the control glades, whereas a disproportional distribution was noticed in soils under larch and birch plantations. Regarding amorphous Fe content, a uniformly distribution was observed in soil profiles under larch and pine plantations, indicating that under these plantations podzolic processes did not occur. Contrary, in soils under birch and fir plantations a disproportional distribution of amorphous Fe was found. This might be due to the fact that the short stagnation of water on more flat areas influenced the redistribution of amorphous Fe in soils.

The content of humus in humus-accumulative layers under all plantations increased compared to open areas due to the addition of organic matter from the forest litter. The results from the fractional composition of humus revealed that the investigated plantations were grown either on mountain chernozems or on leached chernozems. Ratios between humic and fulvic substances revealed that the humus type was as follows: under the pine plantation – mull; under birch and larch plantations – moder; under the fir plantation – moor.

3.5 Hydrological soil properties

3.5.1 Dry bulk density, specific weight and porosity

The dry bulk density, specific weight and porosity data are shown in table 3.7. The dry bulk density of soils under the investigated plantations was lower compared to controls. As can be seen in table 3.7, the bulk density under the investigated plantations was lower in the upper soil layers and increased with the depth of profiles. Generally, the bulk density is related to soil texture and eluvia processes in the soil. However, under the investigated plantations the lower bulk density in the upper soil layers was not related to texture, rather resulted from the penetration of roots and digging fauna.

Birch and fir plantations were growing on mountain loam chernozems formed on carbonate argillaceous slates. The bulk density in the soil under the birch plantation sharply shared the soil profile in two parts. Thus, the top profile till 40 cm had a bulk density value between 0.73-0.83 g cm^{-3}, whereas with increasing the depth the bulk density increased (0.97 g cm^{-3}) (Tab. 3.7). The bulk density under the fir plantation increased with the soil depth as well. Therefore, the soil profile might be also shared in two parts: an upper layer between 10-30 cm with low bulk density (from 0.58 to 0.87 g cm^{-3}) and a deeper layer with moderate bulk density (from 0.98 to 1.00 g cm^{-3}). The soil under the birch plantation had a more friable compactness than the soil under the fir plantation and its neighbouring glade. For example, in the upper soil layer under the birch plantation the bulk density was 0.73 g cm^{-3}, whereas in the control glade was 0.93 g cm^{-3} (Tab. 3.7).

The mountain forest chernozems under pine and larch plantations were formed on carbonate argillaceous slates. In the soil profile under the pine plantation two layers were noticed: a friable layer with the bulk density of 0.74 g cm^{-3} (A1; A2) and a moderate dense layer with the bulk density ranging from 1.02 g cm^{-3} to 1 15 g cm^{-3} (AB; B1, B2). The soil profile under the larch plantation might be also shared into two layers with respect to the bulk density: a first friable layer till the horizon AB with the bulk density between 0.63-0.96 g cm^{-3} and a second moderate dense layer which includes AB, B1 and B2 horizons with the bulk density ranging from 1.03 g cm^{-3} to 1.13 g cm^{-3} (Tab. 3.7). Additionally, in the upper 10 cm layer, the soil under the larch plantation had a lower bulk density than the soil under the pine plantation and its neighbouring glade. This might be explained by different fitoclimatic conditions created under the tree canopies. Thus, under the pine plantation the forest litter was decomposed with high velocity, whereas under the larch plantation the thick litter might prevent the compactness of the upper soil layers.

The specific weight determined in the soils under the investigated plantations and in the control glades ranged between 2.2 - 3.2 g cm^{-3}. The high values of the specific weight will be discussed in the chapter discussion (see Subchapter 4.4).

Tab. 3.7: Dry bulk density, specific weight and porosity of soils under birch, fir, pine and larch plantations and in control glades in the Jylandy boundary (2001)

Trial plots	Soil types	Horizons	Soil depth (cm)	Dry bulk density (g cm^{-3})	Specific weight (g cm^{-3})	Porosity (%)
Birch	mountain-forest chernozem on eluvia loess argillaceous slates	**A1**	0-10	0.73	2.2	67
		A1	10-22	0.81	2.2	63
		AB	22-42	0.83	2.2	62
		B1	42-73	0.97	2.2	56
		B2	73-105	0.97	2.2	56
		BC	105-140	0.97	2.2	56
Control glade	mountain chernozem on eluvia loess argillaceous slates	**A0A1**	0-18	0.93	2.2	58
		A2	18-40	0.94	2.2	57
		AB	40-66	0.98	2.2	56
		B1	66-90	1.00	2.2	55
		B2	90-105	1.00	2.2	55
Fir	mountain-forest cold-dry peaty and leached soil on eluvia loess argillaceous slates	**A'**	0-10	0.58	2.4	76
		A"	15-30	0.87	2.4	64
		AB	30-50	0.98	2.4	59
		B1	50-70	1.00	2.4	59
		B2	70-90	1.00	2.4	59
Control glade	mountain leached chernozem on eluvia loess argillaceous slates	**A0A1**	0-12	0.61	2.2	72
		A2	12-35	0.99	2.2	55
		AB	35-50	1.19	2.2	46
		B1	50-70	1.35	2.2	39
		B2	70-90	1.41	2.2	36
Pine	forest-chernozem on eluvia loess argillaceous slates	**A1**	10-30	0.74	2.4	69
		A2	30-42	0.74	2.4	69
		AB	42-60	1.02	2.5	59
		B1	60-80	1.02	2.5	59
		B2	80-120	1.15	2.6	56
Control glade	mountain leached chernozem on eluvia loess argillaceous slates	**A0A1**	10-20	0.79	2.6	69
		A2	20-50	1.11	2.6	57
		AB	50-80	1.11	2.5	56
		B1	80-100	1.18	2.5	53
		B2	100-120	1.09	2.5	56
Larch	forest-chernozem on eluvia loess argillaceous slates	**A1**	0-10	0.63	2.4	74
		A1	10-30	0.96	2.7	64
		AB	30-50	1.03	2.9*	64
		B1	50-70	1.13	3.2*	64
		B2	70-100	1.13	3.2*	64
Control glade	mountain leached chernozem on loess eluvia loess	**A0A1**	0-10	0.94	2.6	64
		A1	10-40	0.96	2.6	63
		AB	40-67	1.06	2.6	59
		B1	67-82	1.16	2.6	55
		B2	82-100	1.16	2.6	55

Soil porosity was calculated from data of specific weight and bulk density. The soil bulk density affects the soil porosity. A high soil porosity was noticed in the upper A-horizons of the soil profiles and then gradually decreased with the depth. As can be seen from table 3.7, the porosity of soils under the investigated plantations ranged from 76 % to 56 %, whereas in soils under the control glades the porosity varied between 72 % and 36 % (Tab. 3.7).

3.5.2 Water infiltration

Previous investigations showed that the bulk density is related to water infiltration (Revut, 1962; Voronin, 1996). The compaction of the soil leads to a decrease in the infiltration rate (Cheshev, 1978). Data on water infiltration are shown in table 3.8. The investigated soils were characterised by different water percolation. The water infiltration was significantly higher in the upper soil layer (0-10 cm) under the larch plantation compared to the neighbouring control glade. The upper soil layer under the larch plantation was percolated with an average speed of 100 mm min^{-1} within one hour. The total amount of infiltrated water was 6000 mm h^{-1}, whereas in the control glade the soil was infiltrated by 453 mm h^{-1} with an infiltration rate of 8 mm min^{-1}. The soil infiltration rate under the pine plantation was not significantly different than the value found for the control glade. The soil under the pine plantation was infiltrated by 1937 mm h^{-1} and the water percolated with a speed of 32 mm min^{-1}, whereas in the control glade the corresponding values were 687 mm h^{-1} and 11 mm min^{-1}, respectively. The soil water absorption capacity under the birch plantation was 1563 mm h^{-1} and on the control glade 320 mm h^{-1}. Additionally, the water infiltration rate under the birch plantation was 26 mm min^{-1} and in the control glade 5 mm min^{-1}, but these values were not significantly different from each other (Tab. 3.8). No statistically significant differences were found between the infiltration rates under the fir plantation and its control glade. Nevertheless, it can be assumed that forest plantations enhance the water infiltration rate into the soil.

Tab. 3.8: Water infiltration under birch, fir, pine and larch plantations and in the control glades at 20°C and 10 cm soil depth in the Jylandy boundary (2001) (different letters denote significant differences between tree plantations and control glades by the Tukey-test)

Trial plots	**Water infiltration rate (mm min^{-1})** After 2	**5**	**10**	**15**	**30**	**60**	**Total* (mm min^{-1})**	**Mean cumulative infiltration rate (mm min^{-1})**
Birch	160	61	30	27	19	16	1,563	26 **a**
Control glade	67	8	2	3	3	3	320	5 **a**
Fir	173	114	81	73	52	39	3,430	57 **ab**
Control glade	125	59	37	34	30	33	2,217	37 **a**
Pine	140	76	45	36	31	19	1,937	32 **a**
Control glade	83	17	13	15	9	6	687	11 **a**
Larch	337	150	252	144	86	53	6,000	100 **b**
Control glade	75	7	6	6	5	5	453	8 **a**

* cumulative infiltration after 1 hour (mm)

3.5.3 Aggregate size distribution

All physical properties of soil are related to the soil structure. Selected data sets with basic influence on soil structure are summarised in table A6 (see Appendix). The soil under the investigated plantations had a better soil structure compared to the control glades. Regarding the soil structure, from the forest science point of view, the most important aggregate sizes are clod and granular structures (1-5 mm), which were higher in the upper soil layers under all investigated plantations compared to the control soils (see Appendix: Tab. A6). For instance, in soils under birch and fir plantations the fraction of aggregates from 1 mm to 5 mm was important till 20 cm compared to the control glades, while in soils under pine and larch plantations these aggregates formed a large amount till 50 cm of the soil profiles. Additionally, the control soils had more prismatic grain-size particles. In the upper layers of the soil under the control glades, the highest percentage had grains with a diameter > 10 mm (29 %), whereas in soils under the investigated plantations these particles accounted for not more than 4.7 % (see Appendix: Tab A6).

It was also important to determine differences in soil structure under birch, fir, pine and larch plantations, because the improvement soil structure is related to biological properties of trees. The aggregate structure was different between coniferous and deciduous plantations. In the upper soil layers under coniferous trees (fir, pine, larch), it was observed that sizes between 3 mm and 10 mm dominated, whereas under the birch plantation sizes between 2 mm and 5 mm prevailed. The investigated plantations had also a different influence on soil structure within the depth of soil profiles. For instance, in the soil under the larch plantations, the sum of grains between 1 mm and 10 mm was high till 135 cm compared to the control glades, under the pine plantation till 60 cm and under fir and birch plantations till 30 cm (see Appendix: Tab A6).

Because the most significant influence of trees on the soil aggregates is noticed in the upper soil layers, the aggregate size distribution in these layers is summarised in table 3.9. It can be seen that more particles with sizes from 1 mm to 10 mm and from 1 mm to 5 mm were found in the upper soil layers of the investigated plantations compared to the control glades (Tab. 3.9).

Tab. 3.9: Aggregate size distribution (%) in the upper soil layers under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2001)

Trial plots /soil depth (cm)	**Aggregate size distribution (%) – dry sieving**	
	1-10 mm	**1-5 mm**
Birch /0-22	90.9	74.4
Control /0-18	69.0	33.5
Fir /0-15	96.5	68.7
Control /0-12	92.7	64.1
Pine /0-30	90.5	64.6
Control /0-20	90.0	31.6
Larch /0-30	97.1	64.1
Control /0-40	88.1	61.0

Generally, the soil structure determines the aggregate stability which is the main factor to prevent soil from erosion. Data on the aggregate size distribution in the upper soil layers are shown in table 3.10 (see also Appendix: Tab. A7). In the topsoil under fir and pine plantations, the amount of aggregates with sizes of $\geq$ 0.25 mm increased compared to the control glades

(Tab. 3.10). Additionally, a higher amount of aggregates was noticed under the fir plantation than in the soil under the pine plantation (Tab. 3.10). Concerning the amount of aggregates in the soil under birch and larch plantations, a decrease was found compared to the control glades (Tab. 3.10). Moreover, the amount of aggregates (≥ 0.25 mm) was lower in the soil under the birch plantation compared to other investigated plantations. Data also showed that aggregates with sizes of 1-5 mm increased under all investigated plantations compared to the control glades. The same pattern was found in the aggregate size distribution under dry sieving (Tab. 3.10 and Tab. 3.9).

Tab. 3.10: Aggregate size distribution (%) in the upper soil layers under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2001)

Trial plots /soil depth (cm)	**Aggregate size distribution (%) – wet sieving**	
	≥0.25 mm	**1-5 mm**
Birch /0-22	62.4	40.6
Control /0-18	93.2	39.8
Fir /0-15	84.4	57.2
Control /0-12	73.6	37.7
Pine /0-30	91.6	40.4
Control /0-20	90.0	40.2
Larch /0-30	73.6	37.7
Control /0-40	81.1	24.0

3.5.4 Soil texture

The soil texture data are shown in table A8 (Appendix). Based on the fact that the grain-size category with particle sizes < 0.001 mm was approximately 10-30 %, the soils under the investigated plantations are referred as silt loams (see Appendix: Tab. A8). Additionally, in soils under the investigated plantations particles between 0.05-0.01 mm represented 30-40 %. The clay fraction (< 0.001) under the investigated plantations showed an illuvial distribution in the soil profiles. Among all particles, the silt and clay fractions were predominating. In most cases, the percentage of particles from 0.05-0.01 mm was higher in the upper soil layers than in the lower soil layers. The amount of medium silt particles (0.01-0.005 mm) decreased with the depth, whereas the amount of fine silt particles (0.005-0.001 mm) and clay (<0.001 mm) increased, frequently (see Appendix: Tab. A8). This might indicate that the inlet of these particles was from the top of slopes. The increase of clay fractions in the middle and bottom of profiles may be related to forming rock processes (loess argillaceous slates).

3.5.5 Surface and subsurface runoff in forest plantations and control glades

The runoff in a forest and in open areas explicit different. The runoff is conditioned among others by the amount of precipitation that reaches the soil surface and by discrepancies in the structure and properties of the soil (Pobedinskii, 1979). One distinctive feature of forest soils is the presence of forest litter on the soil surface. The forest litter influences the soil water regime and also surface runoff (Monti, 1979). The thickness and the amount of forest litter influence the freezing and thawing of soils (Zaicev, 1965). As shown in subchapter 3.1, the thickness and the amount of forest litter were dependent on the type of plantation.

The water holding capacity of birch, fir, pine and larch litter are shown in table 3.11. It can be therefore seen that the forest litter had a high water holding capacity. The absorbed amount of water was very high under all investigated plantations (Tab. 3.11). However, the water holding capacity of forest litter was dependent on the plantation type. This might be due to differences between deciduous and coniferous species and different accumulation rates of the forest litter under the tree canopies (see Subchapter 3.1). The deciduous birch litter was almost decomposed at the beginning of summer. Therefore, the dry weight of the birch litter was low. Consequently, the birch litter had the weaker water holding capacity during 10 min of water pouring as well as after 24 hours soaking (Tab. 3.11). Among the other forest litter, the thick-peaty larch litter absorbed a significant amount of water, namely 68 ml g^{-1} during short time water pouring and 168 ml g^{-1} after 24 hours soaking (Tab. 3.11). It was also found that the pine litter had lower water hold capacity than the fir litter. The amount of absorbed water in the fir litter was about 69 ml g^{-1} and 85 ml g^{-1} for 10 min and 24 hours, respectively whereas for the pine litter the corresponding values were only 49 ml g^{-1} and 54 ml g^{-1}. This is due to the fact that the fir litter had a higher amount of needles compared to the pine litter (see Tab. 3.1).

Tab. 3.11: Water holding capacity of birch, fir, pine and larch litter in the Jylandy boundary (2001)

Forest litter	**Absolute dry weight (g cm^{-2})**	**Absorbed water (ml g^{-1})**	
		After 10 min of pouring	**After 24 hours soaking**
Birch	7.3	21.1	41.7
Fir	28.0	68.8	85.4
Pine	29.5	48.6	53.8
Larch	30.8	67.9	168.0

Surface and subsurface runoff data are illustrated in figures 3.19-3.22. The relief is the main factor influencing the absorption of water into the soils and surface runoff. The present data also showed that the surface runoff was dependent on the relief of the investigated area. Larch and pine plantations were grown on identical steepness (30-35°) with a tree density factor of 0.8 (Tab. 2.3). However, a lower coefficient of the surface runoff was noticed in the pine plantation (0.5) compared to the larch plantation (0.6) (Fig. 3.21-3.22). The 0.1 differences in the surface runoff between larch and pine plantations might be explained by a lower portion of stable aggregates of 1-10 mm under the larch plantation compared to the pine plantation (Tab. 3.10). Moreover, an important role played also the high humus content in the soil under the pine plantation (Tab. 3.6).

Fir and birch plantations were grown on identical steepness (10-15°) and had the same density of trees. The surface runoff was also related to the canopy closure, which influenced the composition of the forest litter in the investigated plantations (see subchapter 3.1). Since the fir has a denser canopy, the amount of precipitation reaching the soil surface is lower than for the birch tree. Therefore, the coefficient of surface runoff was higher under the birch plantation (0.4) compared to the fir plantation (0.2) (Fig. 3.19-3.20).

As can be seen from figures 3.21-3.22, under the larch plantation the surface runoff was decreased by 0.3 and under the pine plantation by 0.4 compared to the control glades. Additionally, the surface runoff under fir and birch plantations, grown on different slopes than the plantations mentioned above, decreased by 0.7 and 0.2 compared to their neighbouring glades (Fig. 3.19-3.20).

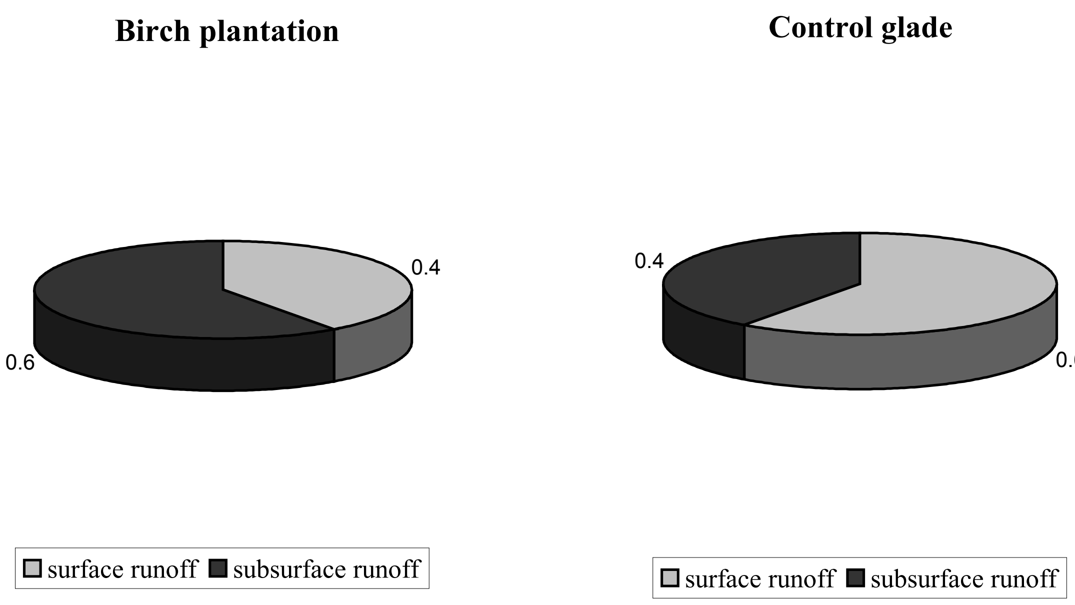


Fig. 3.19: Surface and subsurface runoff in soils under the birch plantation and in the control glade (steepness 10-15°) in the Jylandy boundary (2001)

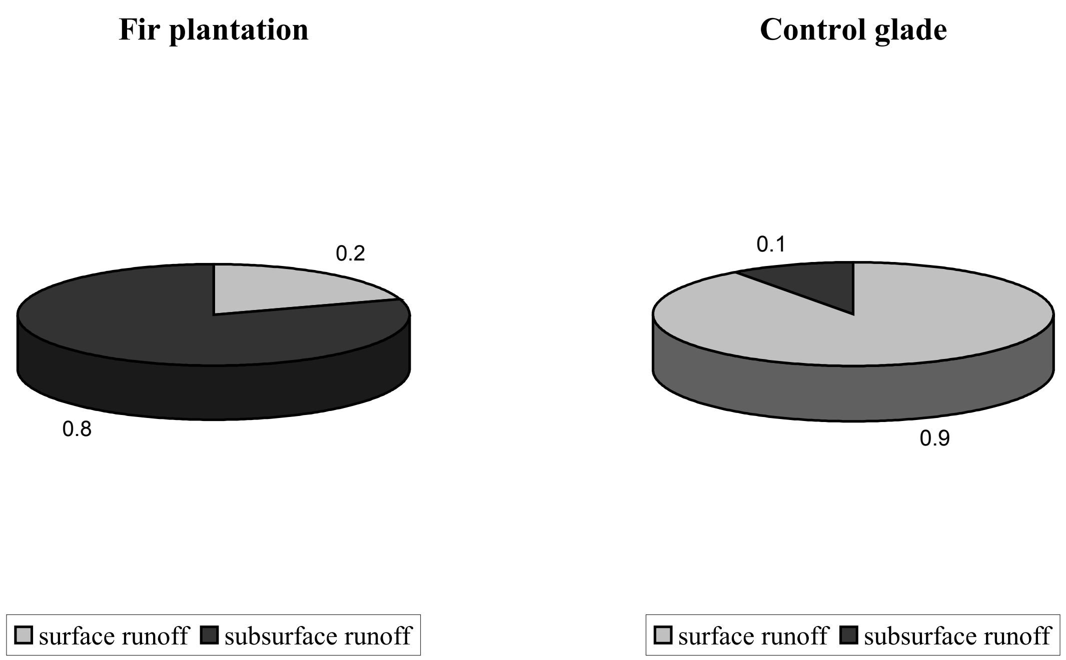


Fig. 3.20: Surface and subsurface runoff under the fir plantation and in the control glade (steepness 10-15°) in the Jylandy boundary (2001)

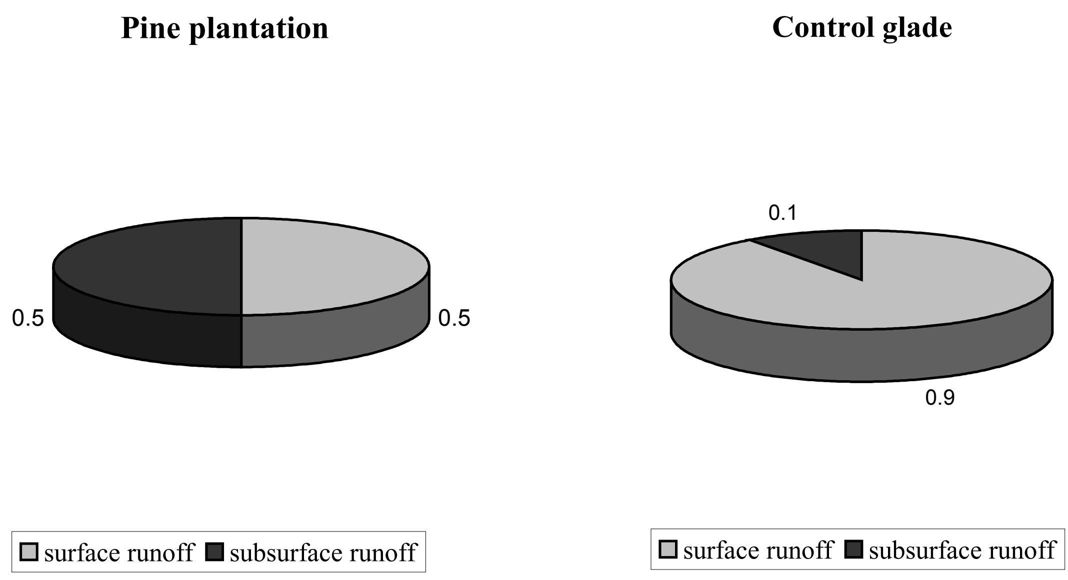


Fig. 3.21: Surface and subsurface runoff under the pine plantation and in the control glade (steepness 30-35°) in the Jylandy boundary (2001)

Fig. 3.22: Surface and subsurface runoff under the larch plantation and in the control glade (steepness 30-35°) in the Jylandy boundary (2001)

Comprising, it could be showed that the dry bulk density in soils under the investigated plantations was lower compared to the control glades. Additionally, data showed that soil porosity under investigated plantations was high compared to the neighbouring glades.

The highest infiltration rate was found under the larch plantation, followed by pine, birch and fir plantations. Compared to the control glades, differences were not all the time consistently significant.

Results from aggregate distribution in soils under the investigated plantations and neighbouring glades showed that forest plantations improved the soil structure compared to the control glades. Under investigated plantations the total amount of aggregates between 1-5 mm increased approximately till 50 cm compared to the control glades. Additionally, the amount of stable aggregates between 1-5 mm increased under all investigated plantations, whereas the amount of stable aggregates ≥ 0.25 mm decreased under birch and larch plantations. Additionally, based on the soil texture analysis soils are referred as silt-clay loams.

The water holding capacity of forest litter revealed that thickness, amount and composition of forest litter influenced the water holding capacity. Data also indicated that all investigated forest litter had a high water holding capacity and absorbed a high amount of water.

Larch and pine plantations were grown on identical steepness (30-35°) with the density of trees of 0.8. However, a lower surface runoff coefficient was noticed in the pine plantation compared to the larch plantation. Fir and birch plantations, grown on slopes of 10-15°, had the same density of trees, while the surface runoff coefficient was higher under the birch plantation compared to the fir plantation. Additionally, data revealed that under the larch plantation the surface runoff decreased by 30 % and under the pine plantation by 40 % compared to the control glades. Additionally, the surface runoff under fir and birch plantations decreased by 70 % and 20 %, respectively compared to their neighbouring glades.

3.6 Soil microbial biomass

The results regarding the soil microbial biomass were obtained by a method, based on the initial respiratory response of microbial populations by amendment with an excess of carbon and energy source. To convert this response rate into a biomass unit it was used a regression equation.

The data of microbial biomass in the soil are illustrated in figures 3.23-3.26. In the upper soil layers under pine and larch plantations, the microbial biomass C increased almost twice compared to the control glades (Fig. 3.25-3.26). On the other hand, a decrease of the microbial biomass C in the upper soil layers was found under the birch plantation compared to its neighbouring glade (Fig 3.23). This might be due to the fact that the birch litter was mineralised on the soil surface and also the high C:N ratio indicates that in the soil under the birch plantation the microbiological activity was low (Fig. 3.9). In the 0-15 cm layer under the fir plantation, the soil microbial biomass C was slightly decreased, but afterwards in the 25-35 cm layer an increase was found compared to the control glade. The compact and thick fir litter might have obstructed the aeration process in the upper soil layer (Fig. 3.24).

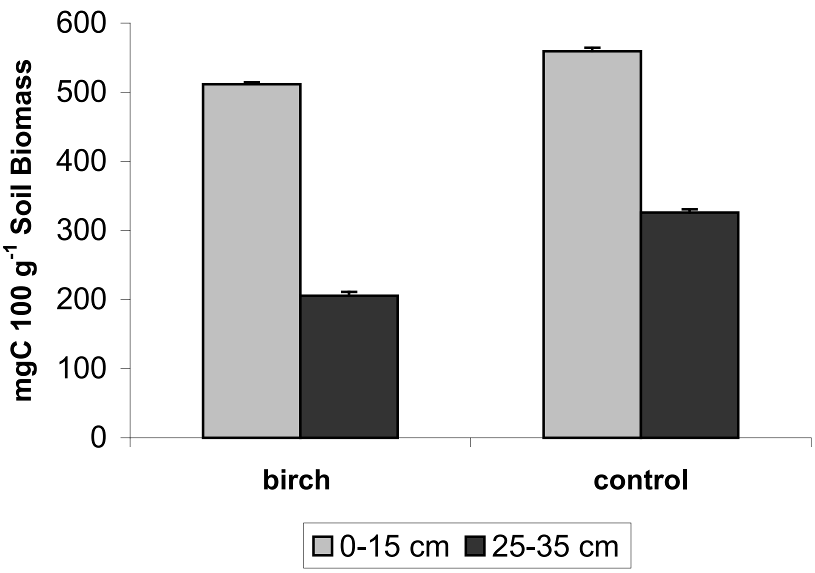


Fig. 3.23: Soil microbial biomass C in soils under the birch plantation and in the control glade in the Jylandy boundary (2000)

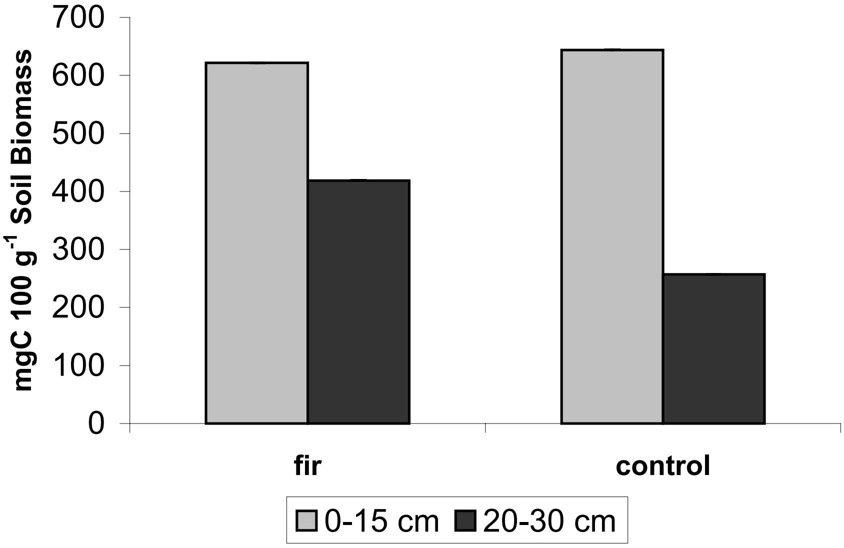


Fig. 3.24: Soil microbial biomass C in soils under the fir plantation and in the control glade in the Jylandy boundary (2000)

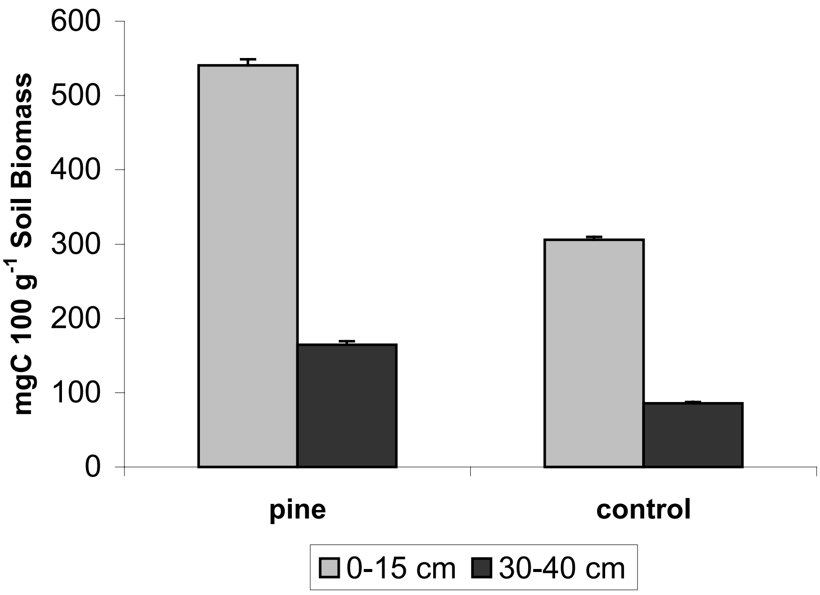


Fig. 3.25: Soil microbial biomass C in soils under the pine plantation and in the control glade in the Jylandy boundary (2000)

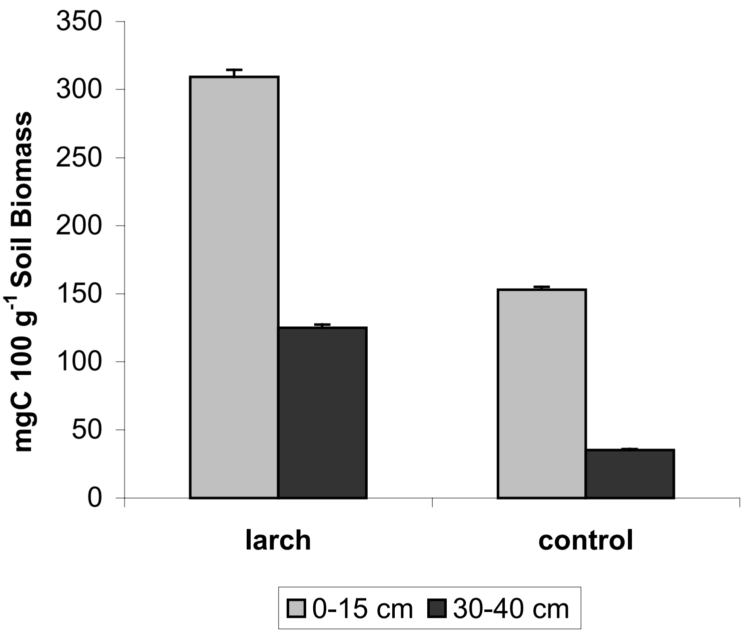


Fig. 3.26: Soil microbial biomass C in soils under the larch plantation and in the control glade in the Jylandy boundary (2000)

Results on soil microbial biomass revealed that microbial biomass C in the upper soil layers under pine and larch plantations increased almost twice compared to controls. However, in the upper soil layers under the birch plantation a decrease of microbial biomass C was found compared to the control glade. The soil microbial biomass in the 0-15 cm layer under the fir plantation was slightly decreased, but afterwards in the 25-35 cm layer an increase was found compared to the control glade.

4 Discussion

The main objective of this research work was to investigate the influence of forest plantations on soil characteristics. Experiments were based on the hypothesis that forest plantations may improve soil properties. To achieve this goal it was necessary to choose forest plantations with the same age of growing. To clarify how forest plantations influence soils under natural conditions in Kyrgyzstan, attention focused on three aspects: forest litter assessment in four different plantations, comparison of vegetative changes between forest plantations and neighbouring glades, and influence of forest plantations on chemical and hydrological soil properties.

The discussion of the results of this thesis starts therefore with a discussion of the forest litter accumulation under different plantations and litter compositions (Subchapter 4.1). In the following chapter, the influence of trees on changes in the vegetation cover is considered (Subchapter 4.2). In the next two chapters, the evaluation of forest plantations influence on chemical and hydrological properties of soils is discussed (Subchapter 4.3 and 4.4).

4.1 Forest litter accumulation and chemical composition of forest litter

Evaluation of forest litter accumulation

The ratio between forest litter accumulation and its decomposition reflects humus dynamics. Favourable natural conditions causes a medium accumulation of the forest litter on the soil surface. A high amount of forest litter leads to the risk of nutrient leaching whilst soil pH is reduced. Zonn (1950) reported a similar effect regarding the release of acidic products by beech litter compounds.

With view to the accumulation of the forest litter it had to be mentioned that the spatial distribution of the litter in mountain forests differs from flat area forests. In flat area forests, the main characteristic of the forest litter accumulation is intra parcel distribution. On the other hand, among the intra parcel forest litter distribution the downhill reallocation of litter due to gravity is also very important in mountain forests. The distribution of the forest litter under the influence of gravity was more evenly in steep slopes under larch and pine plantations. On sites with a lower steepness, as it was found in case of birch and fir plantations, the forest litter accumulation is more dependent on the parcel distribution.

Atkina et al. (2000) reported that the maximum amount of the forest litter was accumulated on the top of slopes and the minimum amount on depressions. The author justified that the bottom of slopes usually is wet and therefore decomposition processes are higher. The investigated sites in the present work were placed in the middle of slopes. This means that the amount of the forest litter accumulated on the soil surface was intermediate. Additionally, the present results showed that the highest amount of the forest litter was accumulated under pine, followed by larch, fir and birch plantations. Similar results were found by Djebisashvili (1983) in experiments carried out in the Caucasus mountains. In this context France et al. (1989), compared 27 years old monocultures grown on agricultural soils in southern Ontario, found that the forest floor mass under paper birch was 60 % lower than under white spruce, and 82 % lower than under white pine.

Malyanov (1939) established that the velocity of decomposition differs between the forest litter fractions. The author ascertained that bark and cones were slowly decomposed. Studies of Stepanova and Muhin (1979) showed that the decomposition of twigs in dry conditions lasted 10-14 years when the forest litter was in contact with the soil. Generally, fungi decomposed the falling materials under dry conditions (Ramensckii, 1971).

The present research work showed that the climatic conditions favoured the decomposition of the forest litter. Owing to the high presence of fungi in the fir litter within L (litter) and F (fermentation) layers, the fractions of twigs, branches and bark were present in smaller amounts than in the larch litter where fungi can penetrate only the F (fermentation) layer. Larch and pine needles were decomposed with high velocity, whereas a reverse pattern was found for fir needles. The weak decomposition of fir needles occurred because of the dense canopy closures and the presence of mosses on the soil surface. Generally, mosses are reducing the speed of decomposition processes in the forest litter. Comparing coniferous litter, in the pine litter a high amount of grass remains was found, which created favourable conditions for the progression of micro-flora. As a consequence, in the pine litter a low amount of needles, twigs and branches was found, whereas cones were present in high percent. This may be due to the fact that cones cannot be decomposed very quickly (Malyanov, 1939). The other fractions were decomposed with high velocity and therefore the cones remained. The low thickness of the pine litter also justifies the fact that decomposition processes in this litter are higher compared to other coniferous litter. The birch litter had the highest amount of grass residues compared to the other forest litter and was almost decomposed. Completely decomposition as well as high amounts of forest litter cannot give a positive effect on soil properties. In this case the nutrients were almost mineralised and because of their leaching in the soil cannot support the trees.

Chemical composition of forest litter

Parcels and micro zones are important for soil properties. The composition of edificators and dominants is affected by the parcel structure of the biogeocenozes. Homogeneous sites formed by identical edificators and dominants are distinguished between the borderlines of the parcel. The soil under these sites is known as tessera. Tessera is characterised by anisotropy, i.e. changes of the soil properties under edificatory, and usually near the tree trunks is noticed a higher amount of forest litter.

In the present work, edificators (i.e. birch, fir, pine, larch) formed different tesseras. As mentioned above, the reallocating of the forest litter in flat areas is mostly dependent on the parcel distribution. Additionally, with increasing the steepness the distribution of the forest litter is also influenced by gravity. On slopes with low steepness found under birch and fir plantations, the variability of acidity between and under crowns was not significant. On the other hand, with increasing the steepness, as in case of pine and larch plantations, significant differences were found regarding the pH value of the forest litter between and under crowns.

The forest litter under pine and larch plantations were slightly acid and under birch and fir plantations they were moderately acid. The differences in the acidity of the forest litter are related to differences in decomposition processes. Usually, coniferous litter are more acidic than deciduous litter. The fact that the fir litter had a moderate acidity may be explained as follows: fir act as a pump, taking up calcium from the deeper horizons of the soil profile and returning it to the soil surface as forest litter.

The special feature of the forest is the capacity to accumulate nutreints in the forest litter and to return them to the soil. Even under unfavourable conditions as found in the northern part of Russia where podzols are formed under the forest, an important role in growing a forest is played by the forest litter. Under podzol processes, besides destroying the organic and mineral parts of the soil, in the upper soil layers occurs the accumulation of nutrients, which are leached from the forest litter. This explains the productiveness of forests grown under such conditions. When grass is grown under canopies, this increases the accumulation velocity of elements from the forest litter in the soil and favours the progress of turf processes.

The important role of the forest litter for soil properties was also reported by Zonn (1950-1954), Antipov-Karatayev et al. (1955), Swift et al. (1979), Blair (1988), Santa Regina (2001).

The natural conditions in the Issyk-Kul area are different compared to the rest of the Tian-Shian territory. The moisture deficiency and low temperatures in the summer period, which influence the decomposition of the forest litter and as a whole the forest soil formation, may explain the low activity of microbiological processes. A previous study of Vuhrer (1962) showed that in the investigated region of Ak-Suu LOH bacteria generally decompose the forest litter. This indicates that in the forest litter a complete decomposition of organic substances till simple compounds occurs and the acidity increases to a neutral level. This is in accordance with the present work, showing that the investigated forest litter were not strongly acid.

The present results showed that all forest litter had a high nutrient content. Also high ash content justifies that in the investigated forest litter coarse humification did not occur. It might be supposed that in the process of forest litter decomposition a high amount of elements was released, which in the absence of systematically water flow were accumulated in the forest litter. It has to be considered that a high amount of calcium in birch, pine and fir litter is an important indicator of the favourable influence of the forest litter on soils. The high content of calcium in the fir litter supports the previous conclusion concerning the fir litter acidity. Samusenko (1965a) and Kojekov (1963) also showed that fir (*Picea shrenkiana*) needles from this area had a higher content of calcium and magnesium compared to fir needles from forests located in Russia, Bulgaria and East Tibet. Previous investigations revealed that deciduous trees usually have fertility-enhancing effects (throw forest litter) on soil properties (e.g. De Kimpe et al., 1976; Miles et al., 1980; Nielsen et al., 1987; Nielsen et al., 1999). For instance, Miles et al. (1980) reported that, particular for birch, increased concentrations of forest floor N, Ca, K and Mg occurred with increasing the proportion of broadleaf occupancy. However, the literature is not unanimous. In modelling study, Binkley et al. (1991) concluded that the nutrient cycling behaviour of birch did not differ greatly from other tree species with similar growth patterns and rates. From the present work findings it can be revealed that the birch litter has a high macronutrient content, but as mentioned above the litter was almost decomposed under natural conditions and therefore cannot contribute to the improvement of soil fertility.

The Jylandy boundary is a non-polluted area. Nevertheless, in the present work the sulphur content in the forest litter was higher compared to the oak litter in a non-polluted forested area in western Spain (Quilchano et al., 2002)

Data obtained by Samusenko (1965a) in the same Jylandy boundary, concerning the chemical composition of the forest litter under birch, fir, pine and larch plantations are summarised in table 4.1 together with data sets of the present study.

Tab. 4.1: Nutrient content (%) in birch, fir, pine and larch litter in the Jylandy boundary – ash analysis (1965 and 2000)

Tree	**Years**	N*	**P**	**Mg**	**Ca**	**Si**
		%				
Birch	**1965**	1.6	0.2	1.4	2.8	7.3
	2002	3.9	0.6	1.8	4.8	27.6
Fir	**1965**	2.6	0.2	2.0	3.2	10.6
	2002	3.5	1.1	1.6	15.4	21.3
Pine	**1965**	1.4	0.1	1.1	1.7	11.1
	2002	4.2	0.8	1.6	13.4	21.9
Larch	**1965**	1.6	0.2	1.1	2.3	9.9
	2002	4.8	1.3	1.0	17.2	21.5

*analysed in dry matter

Comparing the presented results with previous results of Samusenko (1965a), the following ranking order of nutrients in the forest litter can be deduced: Si > Ca> N > Mg > P

With increasing ages in the investigated plantations the ranking order of nutrient contents in the forest litter remained the same. However, it was found that Si, Ca, N and P contents in the forest litter increased compared to the Samusenko data sets (1965a), whereas in fir and larch litter a decrease of Mg content occurred (Tab. 4.1).

4.2 Changes in the vegetative cover under the influence of trees

The ways and methods of human affecting the nature are different. Thus, in the last century the fir forest of Kyrgyzstan was exposed to strong deforestation. For instance, the deforested area (i.e. wood-cutting area) was 276 thousand hectares in 1950 (Aidaraliev, 2001). In order to decrease the deforestation areas, the Forest Institute in Kyrgyzstan carried out experiments since 1945 to introduce different tree species in the belt of fir forest. Therefore, including the open areas in afforestation will lead to changes in the vegetative cover.

The relationship between different structural layers of forests has been studied in many parts of the world for at least 30 years. In North American forests, the correlations between composition and diversity of the canopy and subcanopy layers have most often found to be loose (Glenn-Lewin, 1977; McCune et al., 1981; Bradfield et al., 1984; Rey Benayas, 1995). Contrary to this, Hermy (1988) found a high correlation between stratal gradients in a data set of small isolated deciduous woodlands in Belgium. The European perspective has differed in so far as canopy composition was often regarded as an outcome of management history (including the deliberate planting of tree species, e.g. Simmons et al., 1992), whereas understorey vegetation was considered to reflect environmental conditions.

In the present work, comparing the floristic diversity between investigated plantations and neighbouring glades, it was possible to consider the influence of trees on understorey vegetation. It was therefore revealed that plant species under fir, birch and larch plantations were loose compared to the control glades in a dimension of 31, 7, 3 species, respectively. Contrary, under these natural conditions the diversity of species increased under the pine plantation in relation to the neighbouring glade. The present results are in accordance with previous reports of Hunt et al. (2003) and Gan (1974). Experiments carried out by Hunt et al. (2003) in Northern Ontario revealed that from 1978 to 1998 the diversity of species increased in young dry pine stands and decreased in young spruce stands. Additionally, investigations by Gan (1974), in the same Jylandy boundary, showed that under 15 years old pine trees, 11 species disappeared and 12 new species appeared. Teuscher (1985) reported a reduction of mesophilous woodland herbs and an increase of acidophytes in Swiss *Picea* stands, resulting in a lower richness than in comparable hardwood stands. Similarly, Simmons et al. (1992) found a negative effect of *Picea* on vascular plant cover and diversity, but an increase in the moss layer compared to oak stands in England. On the other hand, Bürger (1991) and Lücke et al. (1997) reported elevated species richness from

German *Picea* stands on acid soils, which also was mainly due to nitrophilous disturbance indicators.

In Russia, Shugaley (1996) showed that meadow-forest and forest grasslands replaced the weed vegetation under pine and larch plantations on dark grey forest soils. The author also reported that at the experimental sites, after 8 years of growing pine plantations with closed crowns, the grassland was almost suppressed. In larch plantations, the understorey vegetation was maintained longer, whereas under fir plantations the vegetation became dead-cover after 20 years.

From the present results it can be concluded that afforestation in the belt fir forest, after 50 years of deforestation areas, undergoes important changes in the vegetative cover. The present work findings showed that under the influence of investigated plantations the meadow-steppe vegetation becomes more mesophilous due to the conditions created under the canopy of trees (e.g. shadowing).

4.3 Chemical soil properties

The evaluation and development of forest management strategies based on nutrient cycling have been a collaborative effort of ecologists, silviculturalists, tree physiologists and forest soil scientists. Nutrient cycling is often the basis for both soil management and forest harvesting schemes. A problem that constantly haunts forest managers is whether their harvesting regimes allow for sustainable forest productivity (Powers, 1999). Defining the soil's role in nutrient cycling as related to mineralisation, exchange reaction, water regime and root depth, it is crucial to define site's ability to maintain the sustainable forest growth.

Soil pH

Likens et al. (1996) provided strong circumstantial evidence that base cation depletion (notably calcium) associated with acid rain was responsible for a significant decline in net primary production at the Hubbard Brook Experimental forest over the last decade. Although the concentration of acidifying agents in precipitation is currently decreasing, so is the concentration of base cation inputs from the atmosphere (Hedin et. al. 1987, 1994). Likens et al. (1996) suggests that it will take many years for ecosystems to return to the predisturbance state. In support to Likens et al. (1996), Wilmot et al. (1994, 1996) found that base cation fertilisation in a base-poor acidic site in Vermont increased the rates of photosynthesis and radial growth and improved crown vigour in sugar maple (*Acer saccharum*).

Biotic processes unrelated to human activity also influence changes in soil acidity and the availability of cations. The mechanisms by which tree species influence soil acidity and exchangeable cations are several fold and include interspecific differences in the uptake of exchangeable cations and anions (Alban, 1982), nitrogen fixation and ensuing nitrification (Van Miegrot et al., 1984), the production of forest litter high in organic acid content (Ovington, 1953) and the stimulation of mineral weathering (Tice et al., 1996).

In the present work there were large interspecific differences in the pH of the soil profiles. This could be observed in the surface and upper soil layers of approximately 50 cm. The present results showed a decrease in the acidity of soil profiles under pine, larch and birch plantations compared to the control glades, whereas in the soil profile under the fir plantation an increase was found. The observed variations in the soil pH might be explained by interspecific differences in the production of organic acids from decomposing forest litter that change the relative quantities of exchangeable base (Ca, Mg) and acid (Al, Fe) cations in soils, as well as differences in the cation uptake and allocation to biomass pools with different turnover times. These findings support previous conclusions concerning birch and fir litter (see subchapter 4.1.). Thus, the birch litter had a sufficient amount of nutrients but almost all were mineralised on the soil surface, influencing the acidification of the soil profile compared to the control. On the other hand, the thick fir litter was rich in Ca and therefore increased the soil acidity. Additionally, the fir litter slowly decomposed. Konova (1966) also found a higher organic acid production and a lower soil pH on sites dominated by species whose forest litter was relatively recalcitrant to the decomposition processes.

In the same Jylandy boundary, in soils under larch and pine plantations (30 years old) and under the birch plantation (10 years old), Samusenko (1965b) did not found variations in pH. The author reported that chernozems in the Jylandy boundary are less exposed to acidification than chernozems in Russia, but it can be expected that with ages the acidity of soils under forest plantations will change. Results from Vehov (1965) revealed that in Russia, on leached chernozems, 20 years old plantations decreased the soil acidity. The work data at hand indicated that with increasing the trees age the soil acidity has changed. Rozanova (1955) also reported that larch plantations grown on chernozems did not influence the soil acidity in juvenile ages, whereas 60 years old larch plantations decreased the soil acidity. In a plantation study with deciduous and coniferous species, Pohiton (1956) found that slightly acid chernozems under trees had a positive effect. This effect contributes to a better solubility of slightly soluble nutrients.

All studies acknowledge that different plant species have different effects on pH and mineral concentrations in the root zone or rhizosphere, and that this influence decreases with increasing the distance from the root.

Macro and micronutrient contents

Sixteen essential elements are required for plant growth. An element is considered essential if plants cannot complete their life cycle without it, and if the element is directly involved in the metabolism of the plant. Three elements, carbon, hydrogen and oxygen are readily available from air and water. The remaining 13 elements are obtained from the soil complex. Six of these elements, called macronutrients, are required in fairly large quantities in plants, usually in excess of 1,000 parts per million (ppm). These are nitrogen, phosphorus, potassium, sulphur, calcium and magnesium. The other mineral nutrients, including iron, boron, manganese, zinc, copper, chlorine and molybdenum, are known as micronutrients and are required in smaller quantities of usually < 200 ppm (Waine, 2003).

In the present work, in soils under the investigated plantations the content of N, P, K and S increased compared to the control glades. The soil content of Ca and Mg is an important indicator of favourable influence of trees. The present data showed that the contents of Ca and Mg in soils under fir, pine and larch plantations increased compared to the control glades, whereas under the birch plantation decreased. Even if the birch litter had a sufficient supply of Ca and Mg, it was almost decomposed and therefore cannot contribute to the soil nutrient content. Furthermore, the decrease of Ca and Mg content in the soil under the birch plantation might influence the humus content and soil structure.

In the present work, the total amount of P, Ca, Mg and S was found in sufficient quantities (> 1000 ppm). Barnes (1998) established that pH value affects the solubility of several elements (Fig. 4.1). According to Figure 4.1, the macronutrients N, K, Ca and Mg are most readily available at soil pH values above 6, but maximum availability of P is restricted to pH 6 and 7. The micronutrients Fe, Mn, Zn, Cu and Co are most available in soils with pH values below 5.5.

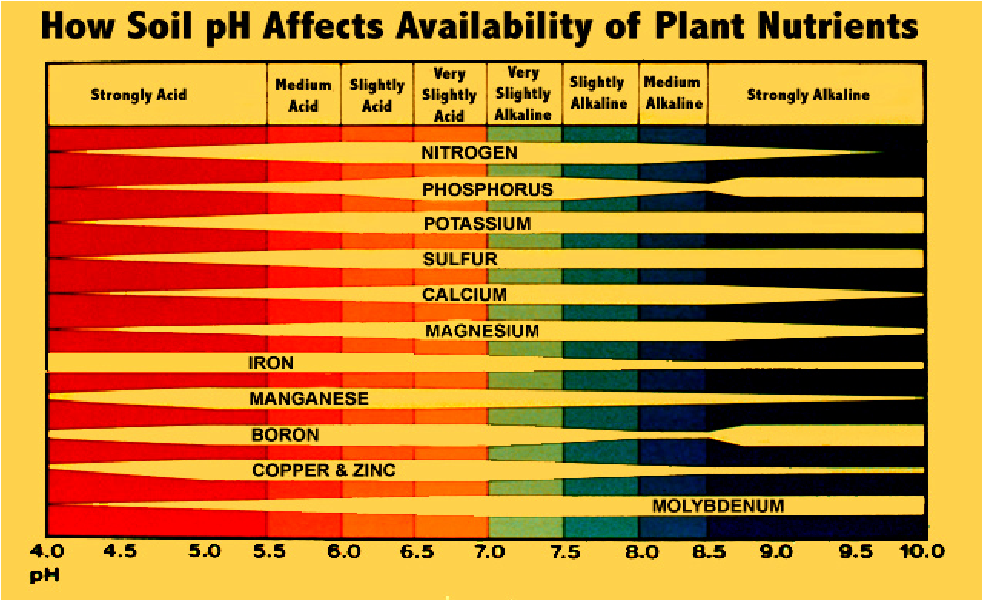


Fig 4.1: Relationship between soil pH and availability of plant micro and macronutrients (modified from Barnes 1998)

Soil pH between 6-7 is considered as optimal for growing deciduous trees and for the uptake of nutrients from the soil (Tinus, 1980). The soil reaction under the birch plantation was neutral, indicating that trees can take up a sufficient amount of nutrients.

Soil pH between 5 and 6 is ideal for the growth of coniferous trees (Tinus, 1980). The present data on soil acidity showed that under the pine plantation the pH was 6, whereas the soil acidity under larch and fir plantations was near 7. During the growth of pine and larch plantations, the soil acidity decreased compared to the control glades. This can be considered as normal for coniferous trees, whereas the fir plantation alkalinize the soil. Probably, this is due to interspecific properties of fir (*Picea shrenciana*), which are grown under these natural conditions (see above). Additionally, in the present work and in the literature reviews (Samusenko 1965b; Mamytov et al., 1977), it was found that glades in the upper soil layers on northern slopes, which are more suitable for cultivation, showed neutral or alkaline soil reactions.

Tab. 4.2: Visual symptoms of macro and microelement deficiency in forest plantations (according to Waine, 2003)

	Plant process	Visual symptoms of deficiency
Macronutrients		
Nitrogen (N)	Production of amino acids and protein. Synthesis of chlorophyll. Growth regulator. Nucleic acids.	Chlorosis of older leaves progressing from pail green to yellow. Colours can mottle. Occasionally scorching of leaves tips and margins.
Phosphorus (P)	High-energy bond (ATP-adenosine triphosphate) associates with energy transfer. Nucleic acids.	Accumulates anthrocyanins, a leaf colour pigment causing blue-green or red – purple coloration. Flowering and fruiting reduced. Lower leaves tend to turn yellow.
Potassium (K)	Opening and closing of stomata, enzyme activity, protein synthesis, photosynthesis and cell growth	Leaf margins become scorched, turn brown or mottled and curl downward. Chlorosis first begins at the tips and margins of leaves towards the base.
Calcium (Ca)	Meristematic tissues of the roots tips, bud elongation and development of fruit. Pectin and cell wall elasticity.	Chlorosis and necrosis of leaves, distorts growth of root tips and shoots.
Magnesium (Mg)	Enzyme systems and chlorophyll synthesis.	Chlorosis of leaves followed by brilliant yellow colour between the leaf veins.
Sulphur (S)	Plant hormones. Three amino acids in synthesis of proteins.	Similarly to N deficiency. Yellowing and necrosis of young leaves resulting from inhibition of protein synthesis. Some stunting of shoot and root tips.
Micronutrients		
Iron (Fe)	Synthesis of chloroplast proteins and various enzymes.	Veins of leaves remain dark green while interveinal tissues become chlorotic light green up to yellow. Dieback of shoots is also common. Easily confused with Mg and Mn deficiencies because symptoms of chlorosis are similar.
Manganese (Mn)	Photosynthesis, respiration, enzyme reactions.	Similar to iron symptoms. Older leaves develop pale, brownish or purple spots.
Boron (B)	Sugar translocation, nucleic acids synthesis and pollen formation.	Dearth or rosetting (witches broom) of apical shoots. Leaves are dwarf and discoloured, becoming chlorotic or necrotic. Terminal and lateral buds and root tips eventually die.
Zinc (Zn)	Plant growth regulators, particularly auxin and indoleacetic acids (IAA). Enzyme reactions.	Chlorosis, bronzing, or mottling of younger leaves. Abscission of older leaves. Terminal nodes have dwarfed or rosette leaves that are closely spaced (short internodes), small and discoloured.
Copper (Cu)	Enzymes	Permanent wilting of leaves; deficiencies difficult to visually detect.
Molybdenum (Mo)	Enzymes in nitrogen fixation	Few symptoms. Pale colour with some scorch on margins of lower leaves. Interveinal chlorosis are similar to symptoms N of deficiencies.
Chlorine (Cl)	Photosynthesis	No visual symptoms

The actual economic market shows that the cultivation of coniferous species is most profitable. However, the setting of nurseries of coniferous species in the Jylandy boundary will demand additional measures. Most of coniferous forests tend to become chlorotic on soils with neutral or alkaline pH because of their inability to take up adequate forms of Fe and Mn (see Tab. 4.2). Also, more acid soils (pH < 4-5) have lower soil fertility, because they do not retain in any degree nutritious cations such as NH_4^+, K^+ and Ca^{2+}. Aldhous (1972) advised against too high soil pH and recommended pH values of 5 for coniferous, of 5.5 for deciduous and of 6 for poplars nurseries.

Soil pH can be reduced by elemental S, aluminium sulphate [$Al_2(SO_4)_3$] or sulphuric acid [H_2SO_4]. Nevertheless, these substances are toxic for conifer seedlings and should be therefore applied before sowing as possible.

The present work data revealed that in soils under the investigated plantations B, Zn and Cu were found in amounts of <200 ppm. The excess of Fe and Mn cannot be toxic for plants because the soil pH was higher than 5.5.

From the ecological point of view, the Zn and Cu soil contents should be also considered. Kyrgyzstan has low industrial emissions. Additionally, the concentration of heavy metals in soils shows major changes under the influence of environmental contaminations in the last decades (Li et al., 1991; Billett et al., 1991). As reported Anderson et al.(1980) and Fridland et al.(1984), the deposition of heavy metals from the atmosphere in forests can be accumulated in the top soil horizons even if these sites are far away from initial sources of pollution. Trüby (2003) reported that the Cu and Zn contents were 104 mg kg^{-1} and 2150 mg kg^{-1} in the soil in old mining territories in the southern black forests near Freiburg. Additionally, the author revealed that the Cu and Zn contents were 109 mg kg^{-1} and 70,000 mg kg^{-1} in the soil of forest plots with recent industrial pollution in the Northern Ejfelevyh mountains near Stolberg. The data of the investigated area showed that the Cu content ranged from 6.4 mg kg^{-1} to 65.2 mg kg^{-1} and the Zn content varied between 33.3 mg kg^{-1} to 290 mg kg^{-1}. Comparing the present findings with the reported data, it can be concluded that soils in the Jylandy boundary are less contaminated. These data can be used as primarily source for further ecological monitoring.

Quantitative and qualitative composition of humus

Soil constitutes a significant reservoir of carbon in organic and in mineral forms and can play an important role in the greenhouse effect by mitigating it throw removing CO_2 from the atmosphere, or conversely contributing carbon to the atmosphere. The total carbon in dead organic matter in the forest floor and in the underlying mineral soil has been globally estimated to be 1450 x 10^9 t C, exceeding the amount stored in the living vegetation by factor two or three (Shlesinger, 1977; Meentemeyer et. al, 1982; Jenkinson, 1988).

Currently, forest plantations occupy globally an area of 187 x 10^6 hectares. However, they account for less than 5 % of the global forest cover (FAO, 2000). Recent trends towards harvesting younger stands include the question how such forest management will impact on soil processes and global carbon sequestration as well as on site productivity and forest biodiversity (Harmon et al., 1990; Johnson, 1992).

In the present work, the total humus content under the investigated forest plantations increased compared to the open areas. The humus accumulation was observed till soil depth of 70 cm under the investigated plantations. The average total humus content in the upper soil layers increased in the order birch < fir < larch < pine. In the same Jylandy boundary, Samusenko (1965b) also found an increase of the humus content under 30 years old pine and larch plantations and 10 years old birch plantation compared to the control glades. Additionally, the author reported a higher humus accumulation in soils under the pine plantation than under larch and birch plantations. In the present work, an increase of the humus content with ages was found and this was in line with Samusenko results (Samusenko, 1965b). Rozanov (1955) also reported that with ages, under fir and larch plantations, the humus content increased in the upper soil layers compared to arable areas. Additionally, Shugalei (1996) showed that the humus content in the upper 10 cm layer was higher under the pine (14 years old) and larch plantation (20 years old) compared to arable areas.

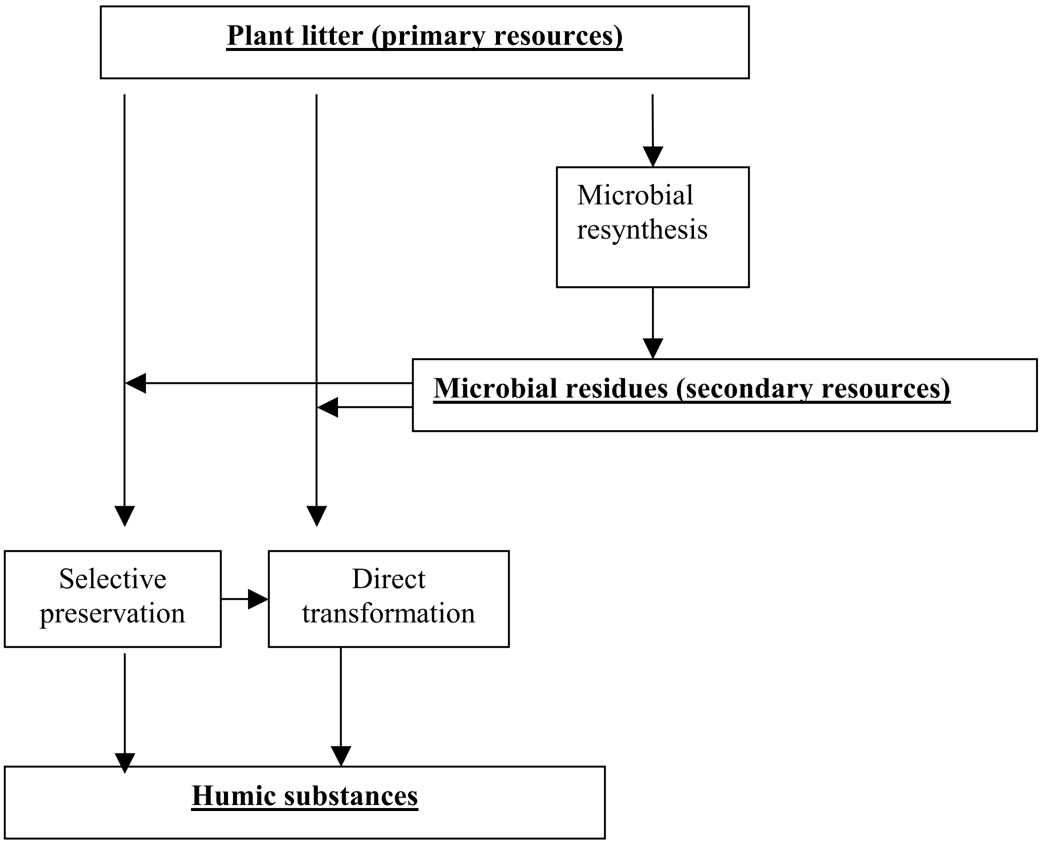
In the present work in the upper soil layers under the pine plantation, a high content of humus of 25.9 % was determined. This might be due to the phenomena that soils in belt fir forest of Kygyzstan are rich in organic matter. Dzens-Litovskaia (1933) revealed that the humus content under the fir forest was from 10 % to 18 %. Afterwards, Assing (1960) reported that soils under the fir forest of Kyrgyzstan accumulated humus between 8-14 % and even more.

The present work data revealed an unequal accumulation of humus between plantations. This might be due to the fact that the amount of the forest litter under the investigated plantations was different and increased in the same order as humus: birch < fir < larch < pine. As mentioned above, the forest litter plays an important role to support the fertility of forest soils. For instance, Vedrova (1996) established that the forest litter annihilation on the surface of dark-grey soils causes decreases in the soil humus content of 18 %. Additionally, Thuille et al. (2000) reported that carbon accumulation rates during afforestation depend on tree species and the length of the rotation. Aaltonen (1940) established that a major indicator of tree influence on soils is the rate of forest litter decomposition under natural conditions. Additionally, the author reported that the humus under “non favourable” trees can be better in good natural conditions than the humus under “favourable” trees in worse natural conditions.

In temperate regions, forest plantations are usually cultivated in areas that did not have forest before and sometimes can cause decreases in soil C. Guo et al.(2002) conducted a meta analysis of the literature on the effect of land use changes on soil C stocks. It was therefore concluded that changing from pasture (including natural grasslands) to conifer plantation the soil C stocks decrease by 12 %. Post et al. (2000) reported that a change from cultivated land to pine-dominated forests in the cool temperate zone resulted in a net loss of the soil organic matter. Additionally, it was shown that in some environments, the growth of woody plants can result in a decrease of the total soil organic C despite the greater production of recalcitrant material, as the inputs are in the surface soil, where decomposition conditions are generally more favourable. However, although land use change can lead to soil C losses, the growth of trees can compensate this carbon source by C accumulation in the living biomass. Laine et al. (1991) evaluated the effects of drainage and forest establishment on the C balance of a peat bog in Finland and found an overall ecosystem C increase of 9 % due to increases in tree, forest litter and peat C, which compensated for any loss of peat C due to increased decomposition rates.

In the forest-steppe and more south climatic conditions, forest plantations are not decreasing the fertility of soils. Such findings were reported in works of Zonn (1954a), Zemlynickii (1954), Pogrebnyk (1948-1956). Additionally, Vacher et al. (1988) found in the Meditarian region that the soil organic matter content under oak trees was twice higher compared to outside the tree canopy. Based on these literature reviews, it can be concluded that in drier climate the organic matter of chernozems under trees may increase.

It is generally accepted that humufication in soils involves a number of processes and that more than one humification process is active in a certain soil. The predominance of specific formation pathways of humic substances in a specific environment presumably depends on the type of precursor material and on the environmental conditions (Ertel et al., 1988; Oades, 1989). The organic matter of forest soils is composed of above-and belowground plant residues (primary resources), microbial residues (secondary resources) and humic compounds (Swift et al. 1979) (Schema 3).



Schema 3: Schematic representation of different humification processes operating on transformation of litter to humic compounds (according to Kögel-Knabner, 1992)

Depending on the decomposition rate, the forest humus types as mull, moder or moor developed. In the present work, data regarding ratios between humic and fulvic substances revealed the following humus types: under pine plantation – mull; under birch and larch plantations – moder; under fir plantation – mor. Previous reports showed that deciduous plantations usually form mull humus types (Rhoades, 1996). The fact that in the present work the humus under the birch plantation had a moder type might be due to mineralisation of the birch litter. As showed by Swift et al. (1979) and Anderson et al. (1989), carbon turnover rates are controlled by three main groups of factors: the site-specific environment (climatic factors like water regime and temperature, interactions with the soil matrix); results in a define resource quality (chemical composition of the forest litter); both factors in turn control the nature and the composition of the decomposer community.

Comparing humic substances and the soil organic matter between control glades, the present work revealed that birch and fir plantations were cultivated on mountain chernozems, whereas pine and larch plantations were grown on leached chernozems.

4.4 Hydrological soil properties

It is well known that forest soil physical properties are distinguished from soil physical properties of nonforested areas. Actually, the physical properties of soils are considered not only as fertility conditions but also as active ecological factors.

Numerous investigations are dedicated to the effect of forest harvesting on forest soil physical properties. For instance, the impact of forest machinery on harvested sites traditionally has been gauged by changes in soil physical properties including bulk density, soil strength, macroporosity, saturated hydraulic conductivity and water infiltration (Gent et al., 1984; Greacen et al., 1980; Lenhard, 1986; Reisinger et al., 1988; Wronski, 1984). Studies about the influence of forest harvesting on soil physical properties in mountain territories were conducted in the Caucasus region (Harashvili, 1986), in Carpathians (Polykov, 1965), in Crimea (Kapluk, 1965) and in Ural (Danilik, 1978; Pobedinskii, 1978).

Two decades ago, Matveev (1984) conducted studies on soil physical properties in the Kyrgyzstan fir forest. Matveev was more concerned on the influence of forest plantations on soil hydrological properties.

The present studies were conducted to prove the influence of birch, fir, pine and larch plantations on bulk density, specific weight, porosity, soil infiltration, soil structure, soil texture as well as surface and subsurface runoff.

At first it is important to define an index, which can be representative for forest and nonforest areas. Important is also that this index has a definite physical and ecological sense and can be easily determined in mountain conditions. Such index is the bulk density. This is in accordance with studies of Revut et al.(1962) and Chan (2002) who decided that bulk density is the primary and defining factor for soil physics.

Bulk density is connected with water-, air- and soil temperature regimes as well as soil biochemical properties and nutrient supplies. The soil gas exchange is connected with bulk density and soil structure. Poiasov (1959) established that the soil air diffusion velocity was a function of macro-structure of soil condition.

Furthermore, the soil compaction has an ecological value because it defines plant growth rates as well as the constitution of root systems in the soil. Already, former results of Pogrebnyak (1948a;b) showed a correlation link between site indexes and soil compactness in the root layers of forest plants. The author revealed that a major reason for the decline of pine plantations on sand grounds was the increase of soil compaction.

In the present work, soils under the investigated plantations had a dry bulk density of 0.58 - 1.4 g cm^{-3} and the porosity ranged between 33-76 %. This means that soils were formed of micro and macro aggregates. It is impossible to compact such soils more than 1.2 g cm^{-3}. A further compaction will result in the breakage of the primary structure. The present work findings of specific weight showed high values between 2.2-3.2 g cm^{-3}. As reported by Maine (2003) most soils have a specific weight from 2.60 g cm^{-3} to 2.80 g cm^{-3}, while it is possible to have a range of values from 2.2-3.5 g cm^{-3}. Any values outside of this first range should be viewed sceptically, as the investigated data revealed (Tab. 3.7). However, these high values will not be discussed in the following chapter.

The soil compaction is also influenced by the soil fauna, especially worms which make the soil compaction more friable. In the present work it was not conducted a special investigation on the soil fauna, but it has been considered that the upper soil layers and the forest litter under the investigated plantations are penetrated by earthworms and insects (see Appendix: Fig. A4-A11). This might indicates that the soil fauna of forest plantations was a major factor for decreasing the bulk density compared to the control glades. Additionally, the present work data revealed that the dry bulk density was significantly lower in the upper layers under the investigated plantations compared to the control glades. This probably was due to the fact that forest plantations have massive root systems, which cause a decrease in the soil compaction more friable compared to grassland in open areas (see Appendix: Fig. A4-A11). The bulk density, estimated in the upper soil layers of the investigated plantations and neighbouring glades, follows the subsequent ranking order: larch plantation > birch plantation > fir plantation > pine plantation.

In the same Jylandy boundary, Matveev (1984) established that 20-28 years old larch and birch plantations positively influenced the bulk density compared to open areas. Additionally, the author revealed that the bulk density under plantations decreased approximately till 30 cm compared to the control glades. The present data revealed that the decrease of the bulk density was approximately in the whole soil profiles under the investigated plantations compared to the control glades. Based on these findings, it might be concluded that with increasing the forest age the influence on bulk density and porosity of soils is activated.

Kosmynin (1986) showed that under 15-20 years old larch and birch plantations, grown in the belt of junipers Kyrgyzstan forest, the bulk density was noticeably decreased in the upper soil layers. The author also revealed that with increasing the forest age the bulk density decreased deeply in the soil profiles compared to open areas.

The bulk density is also related to the infiltration of water into the soil. Increased bulk density results in lower water infiltration rate. In mountain areas, the water infiltration is an important index. Soils with good infiltration capacity will absorb the precipitation, whereas bad infiltrating conditions will lead to erosion.

In the present work, data showed that soils under the investigated plantations had a different infiltration capacity compared to the control glades. The significantly highest infiltration rate was found under the larch plantation, followed by pine, birch and fir plantations. However, not consistently significant differences were found compared to the control glades. This is probably due to the different organic layers on the soil surface under the investigated plantations. The soils under the control glades had a higher bulk density and moisture and therefore lower soil infiltration coefficients were found. Additionally, the upper soil layers in the control glades were penetrated by roots of grasslands such as turf, which influenced the water absorption capacity (see Appendix: Fig. A4-A11). Regarding the Kachinskii scale (Vadunina et al., 1973), a soil infiltration rate of 1000 mm h^{-1} is high, from 1000 to 500 mm h^{-1} is medium and from 500-300 mm h^{-1} is low. The present data showed that water infiltration rates under all investigated plantations were high according to the Kachinskii scale. Based on the same scale, soil infiltration rates were low in the control glades near larch and pine plantations, whereas in the control glades near pine and fir plantations they were medium and high, respectively. From these findings it might be concluded that high infiltration rates under the investigated plantations may reduce the water erosion risk.

It is well known that a better soil structure improves soil physical properties. It is also considered that soils under forests are less structural than under grasslands (Kozlov, 1951). This idea rose primarily from data referring to podzol soils. Podzols are known as soils with a worse structure due to the dominance of SiO_2 and low contents of Ca and humus. Usually, A layers of taiga soils are non-structural or lump-non-structural and B layers have a dense prismatic-massive structure (De Coninck, 1983; Dobrovolskiy 1993). However, mixed birch forest soils are meliorated and have a big lumpy structure. The soil structure improves under deciduous trees in the forest-steppe zone and also under “bairachnimy” forests in the steppe zone.

Since the fifties of the last century, the former opinion that forest degrades soil structure is changed fundamentally (Zonn, 1950; 1954 a,b; 1978; 1982; Zonn et al., 1953). The author established that under oak forests the dark-grey soil in the A-layer with a thickness of 40 cm was characterised by different amounts of structural aggregates from 1 to 10 mm (Tab. 4.3). It was also revealed that during 200 years the total amount of aggregates (1-10 mm) did not decrease.

Tab. 4.3: Total amounts of aggregates and stable aggregates from 1 to 10 mm (according to Zonn, 1954b)

Soil	**total amount of aggregates (1-10 mm)**	**stable aggregates (1-10mm)**
	distribution (%)	
under oak forest (60-70 years)	92	81
under oak forest (200 years)	93	75

Smirnov (1956) revealed that forest soils in the forest-steppe zones of the Mariyskogo ASSR have better soil structure than soils of arable areas. The author showed that in turf-podzol soils the amount of stable aggregates > 0.25 mm was 90 % in the upper layers, whereas in arable soils it was only 17 % due to intensive soil tillage. The same results were reported by Pannikov (1973).

The aggregate distribution plays an important role in soil physics. This was also revealed by the present study. The total amount of aggregates between 1-10 mm increased till 50 cm compared to the control glades. This indicates that roots of trees penetrated more deeply in the soil and glue the soil particles in micro aggregates due to the humus compounds. Therefore, soils under forest plantations have a better structure than under control glades.

The soil structure is connected with physical and chemical processes in the soil. Studies have shown that the recovery and aggregation of depleted stable aggregates may occur under the inflow of new portions of organic compounds, which are the gluey component in coagulation (Gale et al., 2000; Santos et al., 1997). Increased soil aggregation is usually associated with a rising content of soil carbon (Elliott, 1986). Vershinin (1960) reported that gluing process of micro aggregates in macro aggregates as well as of primary particles in micro aggregates occurs not as a result of coagulation. It rather depends on the special physico-chemical nature of humic acids (dipole of molecules) and the capacity of polymerisation. Additionally, the present data showed a high humus content in all investigated plantations that might influence the amount of stable aggregates (1-5 mm).

One factor to prevent soil erosion is the aggregate stability. The amount of stable aggregates between 1-5 mm increased under all investigated plantations, whereas the amount of stable aggregates of ≥ 0.25 mm highly decreased under the birch plantation (Tab. 3.10). These findings are attributed to the fact that under the birch plantation the forest litter was completely decomposed and the total humus content increased slightly, while the nutrients Ca and Mg decreased compared to the control glade.

The soil consists of different particles, which are influencing the soil-forming processes. Physical and chemical soil properties depend on many factors, such as the composition of silt and colloidal fractions. Each fraction of fundamental particles has characteristic physical properties.

Clay soils usually contain more nutrients. Besides this, the clay soils have also a lower water-permeability, poor aeration and unfavourable temperature regime. Sand soils have a better aeration and temperature regimes, but they are poor in organic matter content, nitrogen and mineral nutrients. Loam soils have an intermediate position regarding soil properties and usually are more fertile. The present data revealed that soils under the investigated plantations have a silt-clay texture with the prevalence of silt fractions. Therefore, better hydrological conditions for tree growth were created under the investigated plantations.

In a forest not all precipitation percolates into the soil. Tree crowns detain one part of the precipitation, another part evaporates from forest vegetations, and a further part flows off on the soil surface. The percolated water in soils is spent on the transpiration of forest and grassy vegetation and part of it flows as subsurface runoff into the hydrographical network (Matveev, 1984).

The runoff in forests and open areas is different. One distinctive features of the forest soil is the presence of the forest litter on the soil surface. Soils with forest litter freeze less deeply than soils in open areas. The forest litter reduces the water evaporation from the soil surface. For instance, it was revealed that the evaporation of water from the forest soil surface covered by the forest litter might be reduced by 40-70 % compared to soils without forest litter (Zaicev, 1964).

During the vegetation period, the moisture of forest litter is changed. In the spring time the forest litter is fully saturated. Then, with increasing the plant transpiration the moisture of forest litter is decreased. In the present work, forest litter samples were taken in the summer period (see Subchapter 2.3). Data showed that especially the coniferous litter had a high water holding capacity and therefore this can lead to the transformation of surface runoff into subsurface runoff (Tab. 3.11). One of the most important factors in the protection of forest soils from erosion is the presence of the forest litter on the soil surface. This factor is defined by thickness, amount and its composition. All these characteristics influence the water-holding capacity of the forest litter. Krasnoshekov (1986) reported that in taiga forests the thickness of the forest litter was between 1 cm to 3 cm, the amount of the forest litter varied between 6 t ha^{-1} to 17 t ha^{-1} and the water holding capacity of the litter ranged from 5 mm to 10 mm. On clearing areas, the amount of the litter decreased till 2-8 t ha^{-1} and the water holding capacity changed to 2-5 mm. The influence of forest plantations on surface runoff was reported in several studies (Mergen et al., 1955; Kitredj, 1971). For instance, Mergen et al. (1955) reported that in Oklahoma under oak plantations the surface runoff was 0.01 % and when the forest litter was incinerated the surface runoff increased to 2.5 %. Kitredj (1971) showed that in the northern part of Mississippi under natural oak forest, the surface runoff was 1 %, while on waste lands and on cotton plantations the surface runoff was 47 % and even more.

The relief is one major factor that influences the surface runoff. Harashvili (1986) reported that in Georgia forests, on slopes with 18° steepness, the pine forest and the deciduous-spruce forest decreased the surface runoff by 4-8-fold and 7-12-fold, respectively compared to the open areas. Klincov (1986) revealed that in the Sakhalin mountains under pine and birch forests, grown on 25° steepness, the surface runoff was lowered by 5 % during snow melting in the spring period as well as under heavy rains in the summer period.

The present data also showed that the surface runoff was dependent on the relief. Larch and pine plantations were grown on identical steepness (30-35°) with the density of trees of 0.8. However, a lower coefficient of surface runoff was noticed in the pine plantation compared to the larch plantation. Fir and birch plantations, grown on identical steepness (10-15°), had the same density of trees. The surface runoff was also related to the canopy closure, which influenced the composition of the forest litter in the investigated plantations. Since a fir tree has a denser canopy, the amount of precipitation reaching the soil surface is lower than for a birch tree. This explains the higher surface runoff found under the birch plantation compared to the fir plantation.

The data revealed that under all investigated plantations the surface runoff decreased compared to the control glades. From these results it can be concluded that the surface runoff is an important indicator for assessing the erosion risk. These findings are in line with previous investigations of Kosmynin (1995) and Matveev (1984), Matveev (1984) reported that 30 years old coniferous trees and 13 years old deciduous trees, grown in the belt of fir forest in Kyrgyzstan, decreased the surface runoff compared to the open areas. Soils under forest plantations in the belt of topiary forest in Kyrgyzstan (Kosmynin, 1995) are capable to absorb rains with high intensity as well as to intercept the surface runoff from the top of slopes and transfer this amount of water in subsurface runoff.

4.5 Soil microbiological activity under forest management

The soil air differs from that of the atmosphere by its high CO_2 content as a final decomposition product of the organic matter. The intensity of the biochemical processes taking place in the soil can be interpreted by the amount of CO_2 released. The formation of CO_2 depends to a large extent on the microbial metabolism. Therefore, everything that favours growth of micro-organisms increases the generation of CO_2.

Soil micro-organisms play a critical role in the ecosystem nutrient cycling, facilitating the decomposition of the organic matter, the release of nutrients contained therein and specific processes that influence the flow of these nutrients to plants and hydrological and gaseous losses to surrounding environments (Paul et al., 1996; Bauhus et al., 1999; Groffman et al., 1999). The soil microbial biomass and microbial biomass activity strongly influence the ecosystem retention of C and N and soil fluxes of trace gases (for example, methane and nitrous oxide) that influence the chemistry and physics of the atmosphere (Mooney et al., 1987).

Data in the present work showed that microbial biomass C under pine and larch plantations was higher compared to birch and fir plantations. This is explained by the fact that soils under larch and pine plantations were rich in organic matter, whereas soils under birch and fir plantations had lower humus content. The present data also confirmed that humification processes were higher in soils under pine and larch plantations and lower under the birch plantation. These findings are contrary to results reported by Leitgeb et al. (2003), which revealed that 20 years old birch trees already exerted a positive influence on microbial mineralisation processes. However, Turgay and Haraguchi (2003) found that soil microbial C in cropped plots was comparatively lower than in soil under fruit garden (apricot trees) and forest soil (pine plantations). Additionally, it should be mentioned that the microbial biomass and the activity of micro-organisms in soils are regulated by complex interactions. The supply of organic matter activates the microbial decomposition activity and improves soil physical properties, which regulate the habitat availability and the carrying capacity for soil microbes (Zak et al., 1994; Paul et al., 1996; Bauhus et al., 1999)

Comprising, it can be concluded that coniferous species (especially pine and larch) favourably influence the microbial activity of soils. However, birch trees under these natural conditions had a negative impact on soil microbial biomass C.

5 Summary

The forest area in Kyrgyzstan covers only 4 % of the land area, but it plays a significant role in soil, water and landslide protection. An effective and efficient way to enhance forest unit area productivity and stop erosion processes is to increase afforestation by the introduction of other tree species among Kyrgyzstan fir (*Picea shrenkiana*) mono-species forest. The main objective of the present research work was to investigate the influence of different forest plantations on soil processes including statements to site productivity and sustainability.

The investigations were carried out in birch (*Betula pendula*), fir (*Picea shrenkiana*), pine (*Pinus silvestris*) and larch (*Larix sibirica*) plantations in the Jylandy boundary during 2000-2002.

The main results of the presented work were:

1. Forest plantations influenced the soil mainly by forest litter properties and conditions of their decomposition. The forest litter of the three coniferous and one deciduous plantations contained different fractions (cones, needles, branches, twigs, leaves). The natural conditions were favourable for the decomposition of the coniferous litter, whereas the deciduous birch litter was decomposed with high velocity.

2. Characteristic for Jylandy plantations is a significant supply of the pine litter on the soil surface followed by larch, fir and birch litter. Chemical analysis revealed that all the investigated forest litter were rich in nutrients.

3. Differences were found with respect to the acidity of forest litter. The steepness of slopes significantly influenced the acidity under and between crowns in pine and larch plantations, whereas no significant differences were revealed under and between crowns in birch and fir plantations, grown on more flat slopes.

4. The afforestation of open areas causes to changes in the vegetative cover. Under the influence of trees (birch, fir, pine and larch) the meadow-steppe vegetation on soils becomes more mesophilous due to the conditions created under the tree canopies.

5. A decrease in the acidity of the soil profiles under pine, larch and birch plantations was found compared to the control glades, whereas in the soil profile under the fir plantation an increase was noticed.

6. In soils under the investigated plantations the content of N, P, K and S increased compared to the control glades. Regarding the soil content of Ca and Mg, an increase was observed under fir, pine and larch plantations compared to controls, while under the birch plantation the concentration of both elements decreased. Data regarding the C:N ratio in soils showed that this was optimum under fir, pine and larch plantations.

7. The micronutrient contents in soils under fir and pine plantations were found at higher levels compared to the control glades, whereas a disproportional distribution was revealed under larch and birch plantations.

8. The amorphous Fe was uniformly distributed in the soil profiles under larch and pine plantations, while a disproportional distribution of this element was found under birch and fir plantations.

9. The total humus content under all investigated plantations increased compared to the control glades till the depth of 50 cm. The accumulation of the humus is correlated with the amount of the forest litter.

10. Data regarding ratios between humic and fulvic substances revealed that the humus type was as follows: under pine plantation – mull; under birch and larch plantations – moder; under fir plantation – mor.

11. The dry bulk density decreased compared to the control glades in the following ranking order: larch plantation > birch plantation > fir plantation > pine plantation. The data also revealed that soils under the investigated plantations consisted of micro and macro aggregates.

12. Data showed that soils under forest plantations have a better structure than the control glades. Under the investigated plantations, the total amount of aggregates between 1-5 mm increased approximately till 50 cm compared to the control glades. Additionally, in the upper soil layers, the amount of stable aggregates between 1-5 mm increased under all investigated plantations, whereas the amount of stable aggregates $\geq$ 0.25 mm decreased under birch and larch plantations. Data also revealed that soils under the investigated plantations are referred as silt loams.

13. The highest infiltration rate was found under the larch plantation followed by pine, birch and fir plantations. Compared to the control glades, differences were not all the time consistently significant.

14. The forest litter had a high water holding capacity and absorbed a high amount of water under all investigated plantations. Additionally, data revealed that the thickness, the amount and the composition of the forest litter influenced the water-holding capacity.

15. The surface runoff in forest areas is a function of slope gradient, density and thickness of the litter layer. The surface runoff under the investigated forest plantations was generally lower compared to the control glades. The following ranking order of the surface runoff for the investigated plantations could be observed: fir plantation < pine plantation < larch plantation < birch plantation.

16. Data on soil microbial biomass revealed that in the upper soil layers under pine and larch plantations microbial biomass C increased almost twice compared to controls. Contrary results were found in case of birch and fir plantations because the litter was almost decomposed under the birch plantation, whereas under the fir plantation the thick litter obstructed the aeration process in the upper soil layer.

The results of this work revealed that the forest litter, especially under coniferous plantations, have favourable physico-chemical properties, are rich in chemical elements and play a main role in supporting the fertility of forest soils. Coniferous plantations under natural conditions in Kyrgyzstan increased the soil fertility. However, investigations on the biochemical "forest-soil" cycle should be evaluated within site-specific characteristics.

Forest plantations can be an efficient indicator for assessing the erosion risk in mountain areas of Kyrgyzstan. Thus, it will be economically more profitable to create mixed plantations pine/fir or larch/birch on the northern expositions. A very important task in future is to avoid the creation of mono-species birch plantation.

Zusammenfassung: Einfluss verschiedener Baumarten auf die Parameter der Bodenqualität unter Aufforstungen in Kirgisien

Etwa 4% der Landesfläche Kirgisiens sind bewaldet, dennoch haben diese Areale eine wichtige Bedeutung für den Boden- und Wasserschutz.

Die Aufforstung zusätzlicher Flächen und die Einführung weiterer Baumarten zu der vorherrschenden Fichtenmonokultur stellt eine effektive Möglichkeit zur Verbesserung der Standortproduktivität dar, und führt gleichzeitig zu einer Reduzierung von Erosionsschäden.

In der vorliegenden Arbeit wurde der Einfluss von Aufforstungen mit unterschiedlichen Baumarten auf den Boden untersucht. Zusätzlich wurden auch Aspekte zur Standortproduktivität und der Nachhaltigkeit berücksichtigt.

Die Untersuchungen wurden in Birken-, Fichten-, Kiefer- und Lärchenanpflanzungen im Julandy-Gebiet während der Jahre 2000 bis 2002 durchgeführt und lieferten folgende Ergebnisse:

1. Der Boden wird besonders durch die Eigenschaften der Streu, sowie deren Abbaubedingungen unter forstlicher Nutzung beeinflusst. Die Waldstreu unter den drei Nadelbäumen und dem Laubbaum setzte sich aus verschiedenen Bestandteilen zusammen (Zapfen, Nadeln, Zweige, Blätter). Die natürlichen Gegebenheiten begünstigten die effective Zersetzung der Nadelstreu, während der Abbau der Birkenstreu stark beschleunigt wurde.

2. Charakteristisch für das Julandy-Gebiet ist das hohe Aufkommen von Kiefernstreu auf der Bodenoberfläche, gefolgt von Lärchen-, Fichten- und Birkenstreu. Chemische Analysen ergaben einen hohen Nährstoffgehalt dieser Waldstreu.

3. In Bezug auf den pH-Wert der Streu wurden Unterschiede gefunden. Auf den starken Hangneigungen der Kiefern- und Lärchenstandorte zeigten sich signifikante Unterschiede in der Azidität unter und zwischen den Baumkronen, während auf den flachen Standorten, die mit Birken und Fichtenbeständen aufgeforstet wurden, keine Signifikanz festgestellt wurde.

4. Die Aufforstungen offener Flächen bewirkte eine Veränderung der Bodenvegetation. Unter dem Einfluss der Bäume (Birke, Fichte, Kiefer und Lärche) entwickelte sich eine

mesophile Vegetation, aufgrund der geänderten Bedingungen unterhalb des Kronendaches der Bäume.

5. Im Vergleich zu den Kontrollflächen (Lichtungen) wurde in den Kiefern-, Lärchen- und Birkenanpflanzungen eine Abnahme der Azidität verzeichnet, während die Bodenprofile unter Fichten einen zunehmenden Säuregrad aufwiesen.

6. In den Böden der Aufforstungen lagen die Gehalte an N, P, K und S höher, verglichen mit den Kontrollflächen. In Bezug auf die Elemente Ca und Mg wurden höhere Werte unter Fichte, Kiefer und Lärche gefunden, während der Boden unter Birke geringere Gehalte beider Elemente aufwies. Das C:N Verhältnis zeigte optimale Werte unter Fichte, Kiefer und Lärche.

7. Die Gehalte an Mikronährstoffen in Böden unter Fichte und Kiefer waren höher als in den Böden der Kontrollflächen, im Gegensatz zu niedrigeren Werten unter Lärche und Birke.

8. Eine gleichförmige Verteilung von amorphem Eisen zeigte sich in den Bodenprofilen unter Lärche und Kiefer. Unter Fichte und Birke war im Gegensatz dazu eine unregelmäßige Verteilung dieses Elements erkennbar.

9. Verglichen mit den Kontrollflächen nahm in allen untersuchten Anpflanzungen der Gesamt-Humusgehalt bis in eine Tiefe von 50 cm ab. Die Humusakkumulation korreliert mit der Menge an Waldstreu.

10. Die Verhältnisse von Humin- und Fulvinstoffen zeigen folgende Humusformen in den Anpflanzungen: unter Kiefer – Mull; unter Birke und Lärche – Moder; unter Fichte – Rohhumus.

11. Die Lagerungsdichte der Böden in den Pflanzflächen nahm im Vergleich zu den Kontrollflächen in nachstehender Reihenfolge ab: Lärchenpflanzung > Birkenpflanzung > Fichtenpflanzung > Kiefernpflanzung. Das Bodengefüge unter den Baumanpflanzungen enthält sowohl Grob- als auch Fein-Aggregate.

12. Im Gegensatz zu den Kontrollflächen wiesen die Pflanzflächen eine gute Bodenstruktur auf. Der Vergleich zeigte eine Zunahme an Aggregaten zwischen 1-5 mm unter den Baumbeständen bis in eine Tiefe von annähernd 50 cm. In den oberen Bodenschichten

nahmen stabile Aggregate zwischen 1-5 mm zu, während die Menge der stabilen Aggregate $\geq$ 0.25 mm unter Birke und Lärche abnahmen. Die Bodenart unter den Anpflanzungen wird als schluffiger Lehm angesprochen.

13. Die Infiltrationsrate lag in der Lärchenanpflanzung am höchsten, gefolgt von Kiefer, Birke und Fichte. Die Unterschiede zu den Kontrollflächen waren nicht durchgängig signifikant.

14. Die Waldstreu besitzt eine hohe Wasserspeicherkapazität und absorbiert eine große Wassermenge unter allen untersuchten Pflanzungen. Die Mächtigkeit der Auflage, die Menge und die Zusammensetzung der Waldstreu bestimmt die Wasserspeicherkapazität.

15. Der Oberflächenabfluss im Wald ist eine Funktion der Hangneigung sowie der Dichte und Mächtigkeit der Streuauflage. Der oberirdische Abfluss war in den untersuchten Aufforstungen grundsätzlich geringer als in den Lichtungen. Nach der Menge ihrer Oberflächenabflüsse sortiert, ergab sich für die Pflanzungsflächen folgende Reihe: Fichtenpflanzung < Kiefernpflanzung < Lärchenpflanzung < Birkenpflanzung.

16. Die Erfassung der mikrobiellen Biomasse in den oberen Bodenschichten unter Kiefer und Lärche lieferte für Kohlenstoff fast die doppelte Menge, verglichen mit den Daten aus den Kontrollflächen. In Birken und Fichtenanpflanzungen wurden geringere C-Gehalte gemessen, zum einen aufgrund der schnellen Zersetzungsprozesse unter Birke, zum anderen wegen der fehlenden Durchlüftung des Oberbodens durch eine dicke Streudecke unter Fichte.

Die Ergebnisse dieser Arbeit zeigen, dass die Waldstreu günstige physikalisch-chemische Eigenschaften besitzt, reich ist an chemischen Elementen und eine wichtige Rolle für die Bodenfruchtbarkeit in Wäldern spielt. Die Aufforstungen mit Nadelhölzern in den natürlichen Gegebenheiten Kirgisiens erhöhten die Bodenfruchtbarkeit. Dennoch sollten Untersuchungen über den biochemischen Kreislauf „Wald-Boden" auch standortspezifische Charakteristika in ihre Bewertungen mit einbeziehen.

Aufforstungsflächen stellen effiziente Indikatoren für die Einschätzung der Erosionsgefahr in den Bergregionen von Kirgisien dar. Aus den Untersuchungen lässt sich ableiten, dass gemischte Kulturen, wie Kiefer/Fichte oder Lärche/Birke in den nördlichen Regionen wirtschaftlich vorteilhaft sind, Birken-Monokulturen sind aufgrund der vorliegenden Ergebnisse zukünftig zu vermeiden.

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8 Appendix

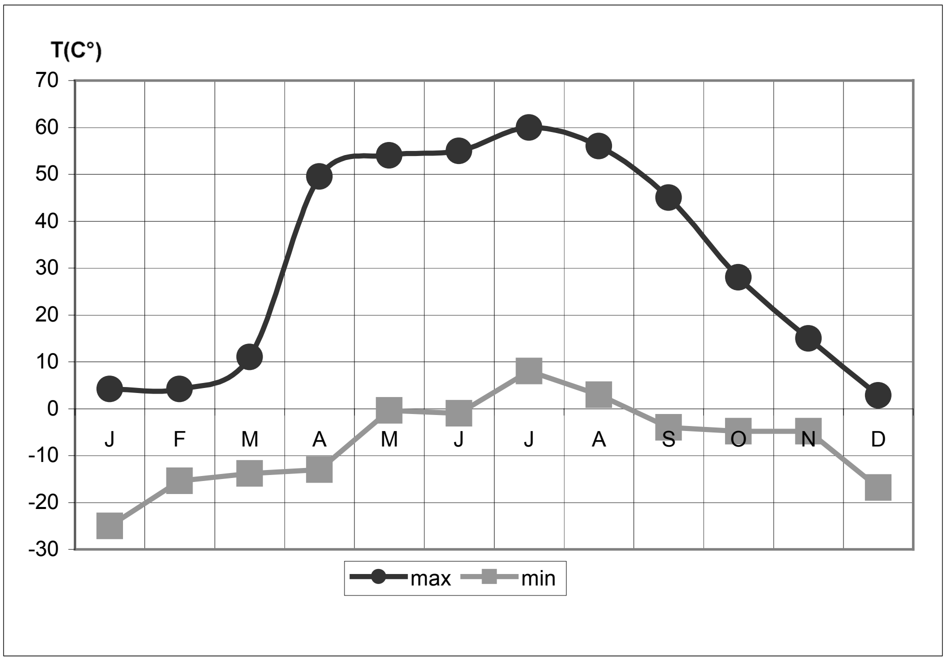


Fig. A1: Monthly maximal and minimal soil temperature at the meteorological station (heat sum in soil depth between 10-20-40-80-160-360 cm); 1950 meter above see level in the Jylandy boundary (2000)

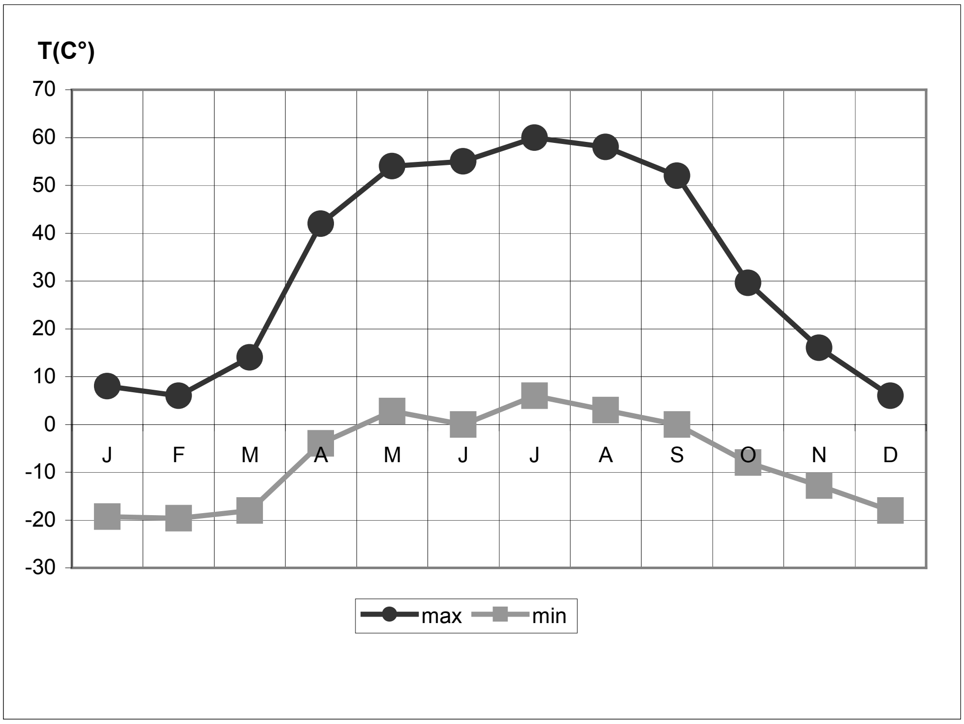


Fig. A2: Monthly maximal and minimal soil temperature at the meteorological station (heat sum in soil depth between 10-20-40-80-160-360 cm); 1950 meter above see level in the Jylandy boundary (2001)

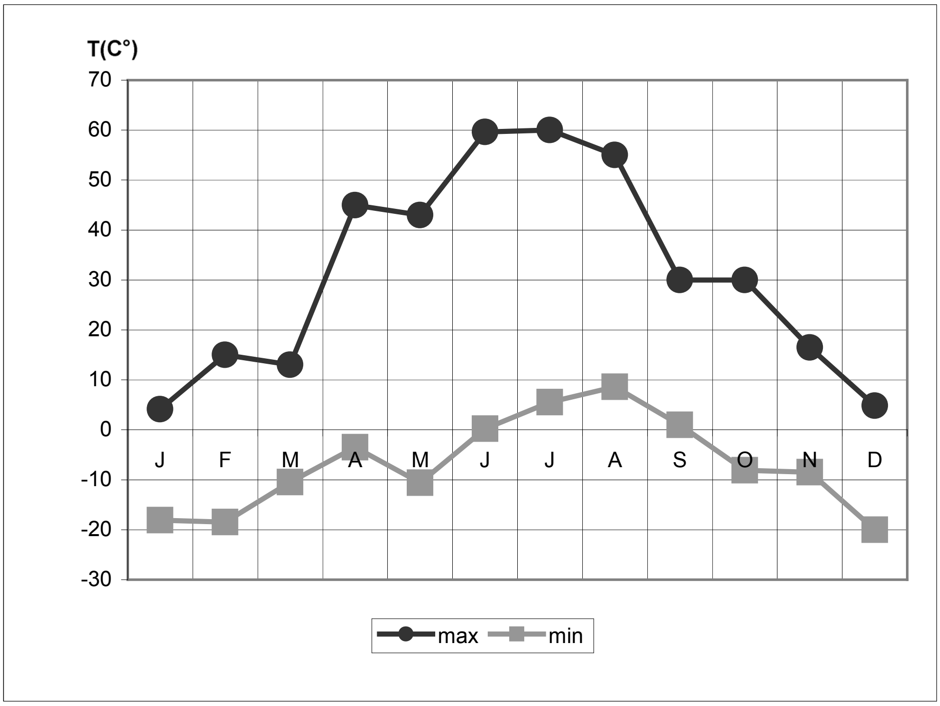


Fig. A3: Monthly maximal and minimal soil temperature at the meteorological station (heat sum in soil depth between 10-20-40-80-160-360 cm); 1950 meter above see level in the Jylandy boundary (2002)

Tab. A1: Amount of birch, fir, pine and larch litter on the experimental sites in the Jylandy boundary (2000)

Samples	**Litter amount (t ha^{-1})**			
	Birch	**Fir**	**Pine**	**Larch**
1	0.361	0.330	0.685	0.445
2	0.268	0.681	1.059	0.660
3	0.321	0.558	0.900	0.720
4	0.606	0.550	1.486	0.850
5	0.234	0.373	0.656	0.486
6	0.177	0.517	0.696	0.464
7	0.341	0.643	0.943	0.564
8	0.244	0.512	0.887	0.488
9	0.247	0.570	0.639	0.397
10	0.227	0.740	0.673	0.719
11	0.261	0.674	0.409	0.531
12	0.288	0.740	0.638	0.509
13	0.306	0.202	0.867	0.495
14	0.331	0.412	0.913	0.479
15	0.208	0.429	1.517	0.371
16	0.220	0.445	0.309	0.468
17	0.161	0.501	0.671	0.479
18	0.458	0.278	1.036	0.550
19	0.353	0.432	0.771	0.442
20	0.230	0.521	1.243	0.531
21	0.203	0.326	1.340	0.467
Sum	**6.04**	**10.43**	**18.34**	**11.12**
Mean	**0.56**	**0.98**	**1.71**	**1.04**

Tab. A2: Acidity (pH) of birch, fir, pine and larch litter (2000)

Samples	**pH of litter**			
	Birch	**Fir**	**Pine**	**Larch**
1	6.6	6.4	6.0	5.6
2	6.4	6.5	6.1	5.6
3	6.5	6.4	6.0	5.5
Mean	**6.5**	**6.4**	**6.0**	**5.6**

Tab. A3: Acidity (pH) of birch, fir, pine and larch litter under and between crowns in the Jylandy boundary (2000)

Samples	**pH of litter**	
	Under crowns	**Between crowns**
Birch 1	6.5	6.6
Birch 2	6.5	6.7
Birch 3	6.5	6.6
Mean	**6.5**	**6.6**
Fir 1	6.5	6.6
Fir 2	6.5	6.6
Fir 3	6.4	6.7
Mean	**6.5**	**6.6**
Pine 1	5.9	6.3
Pine 2	6.0	6.5
Pine 3	6.1	6.4
Mean	**6.0**	**6.4**
Larch 1	5.5	6.0
Larch 2	5.6	6.1
Larch 3	5.7	5.9
Mean	**5.6**	**6.0**

Tab. A4: Ash element content (%) of birch, fir, pine and larch litter in the Jylandy boundary (2000)

Litter	**Ash**	**Si**	**Fe**	**Ti**	**Mn**	**Al**	**Ca**	**Mg**	**K**	**Na**	**P**
	%										
Birch	8	27.6	4.88	0.42	0.21	7.67	6.08	1.76	2.82	1.26	0.57
Fir	11	21.3	3.45	0.33	0.15	5.92	19.65	1.59	2.82	0.98	1.10
Pine	15	21.9	3.56	0.33	0.12	7.22	17.07	1.57	3.04	1.04	0.81
Larch	5	21.5	2.30	0.26	0.18	4.87	22.02	0.99	3.00	0.80	1.28

Fig. A4: *Soil profile 1*

Data: **26.06.2000**

Place: **boundary Jylandy**

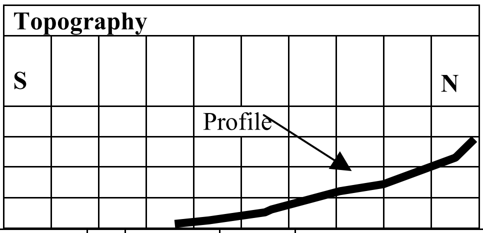
Height (h.a.s.l) : **2050 m**

Trial plot: **birch plantation**

Geology: **loess argillaceous slates**

Exposition: **NE**

Steepness: **10-15°**



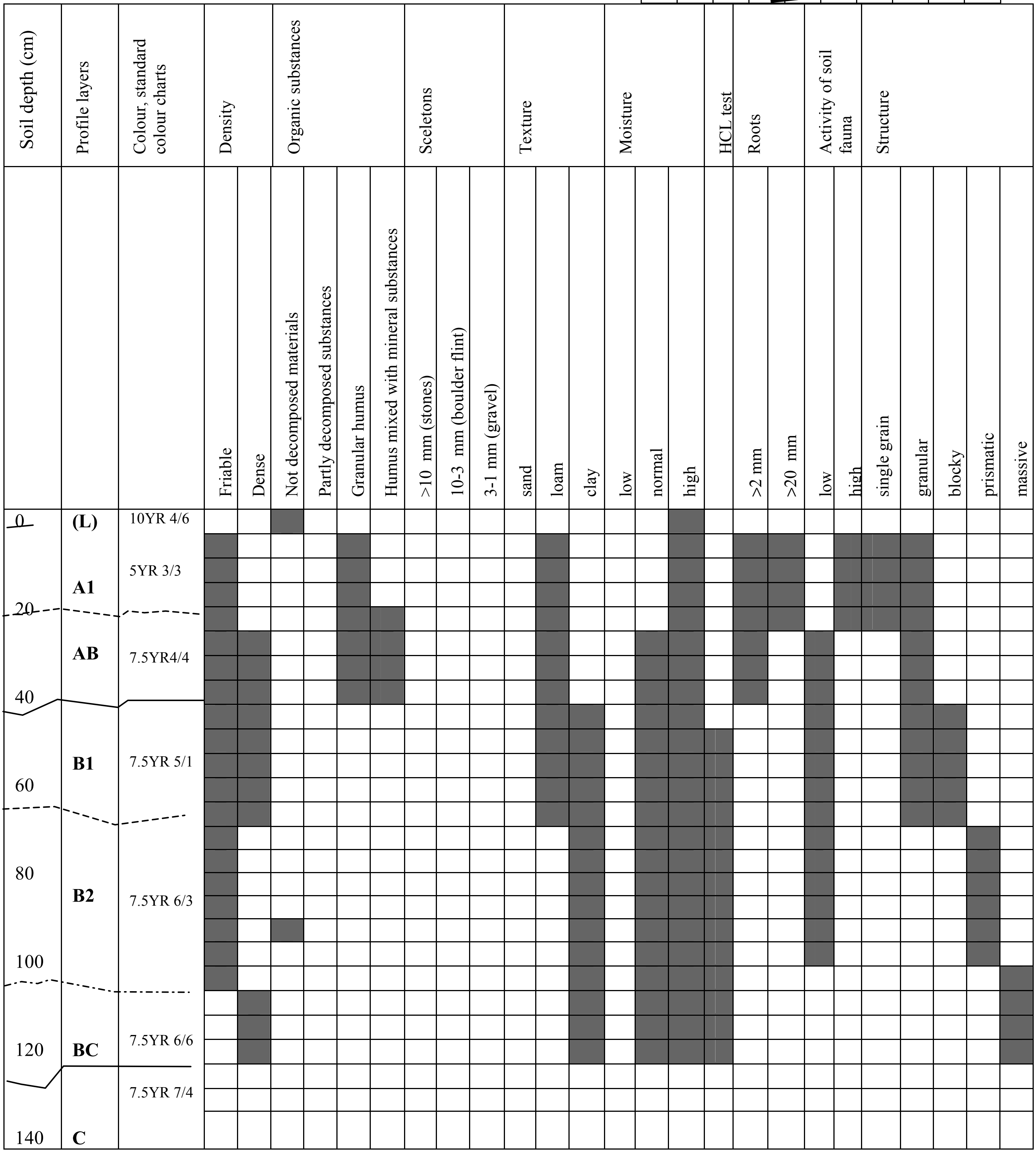


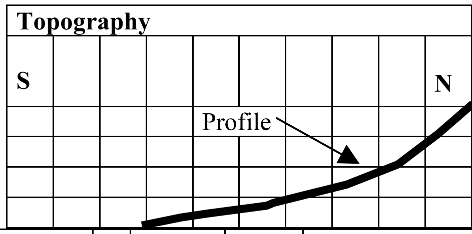
Fig. A5: *Soil profile 2*

Data: **26.06.2000**
Place: **boundary Jylandy**

Height (h.a.s.l) : **2050 m**

Trial plot: **control glade near the birch plantation**
Exposition: **NE**

Geology: **loess argillaceous slates**
Steepness: **10-15°**



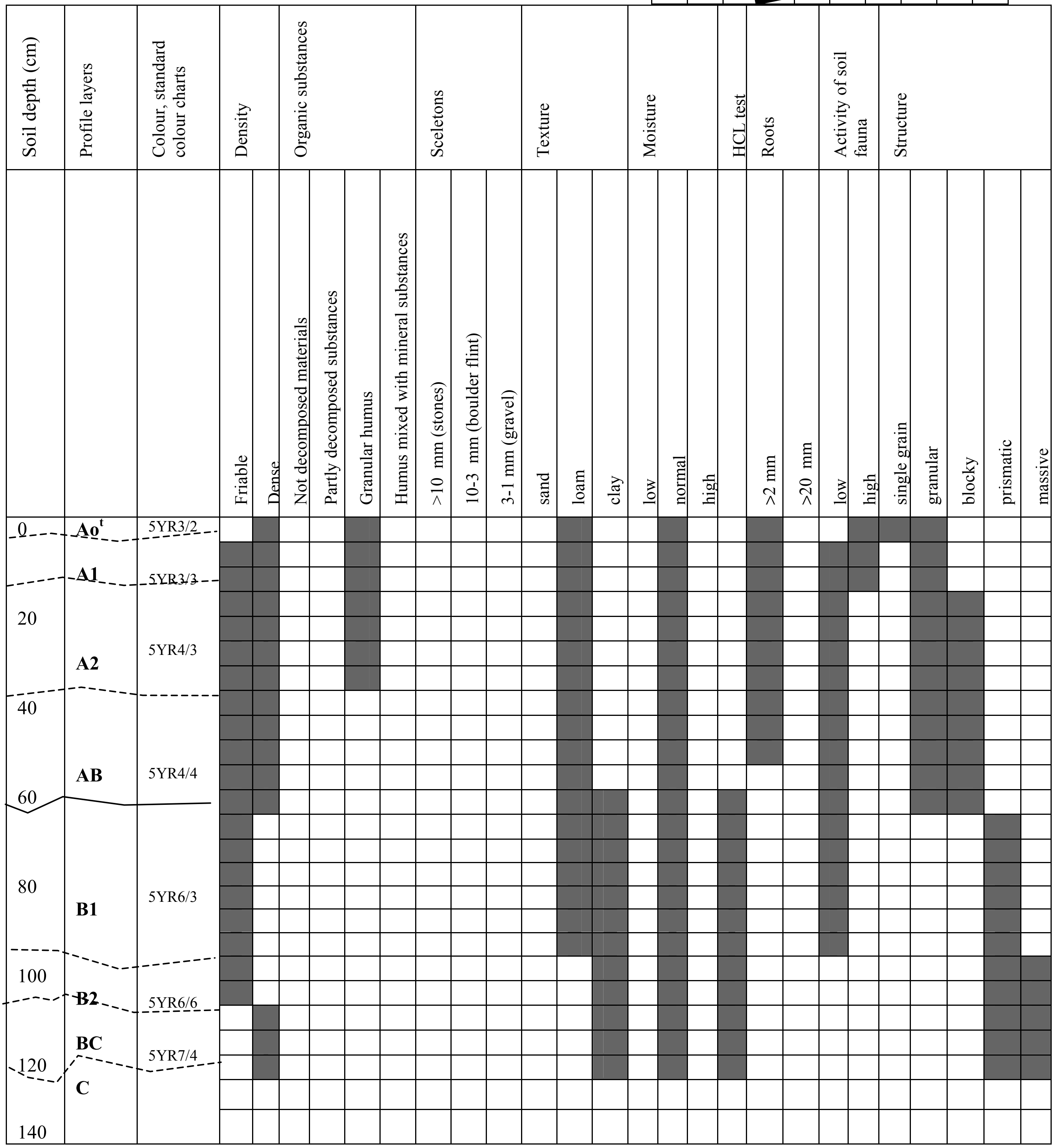


Fig. A6: *Soil profile 3*

Data: **27.06.2000**
Place: **boundary Jylandy**

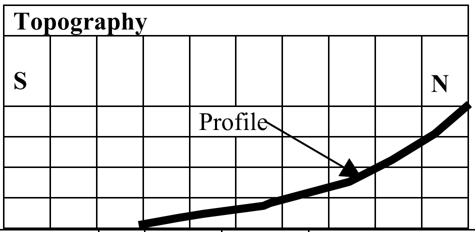
Height (h.a.s.l) : **2050 m**

Trial plot: **fir plantation**

Geology: **loess argillaceous slates**

Exposition: **NE**

Steepness: **10-15°**



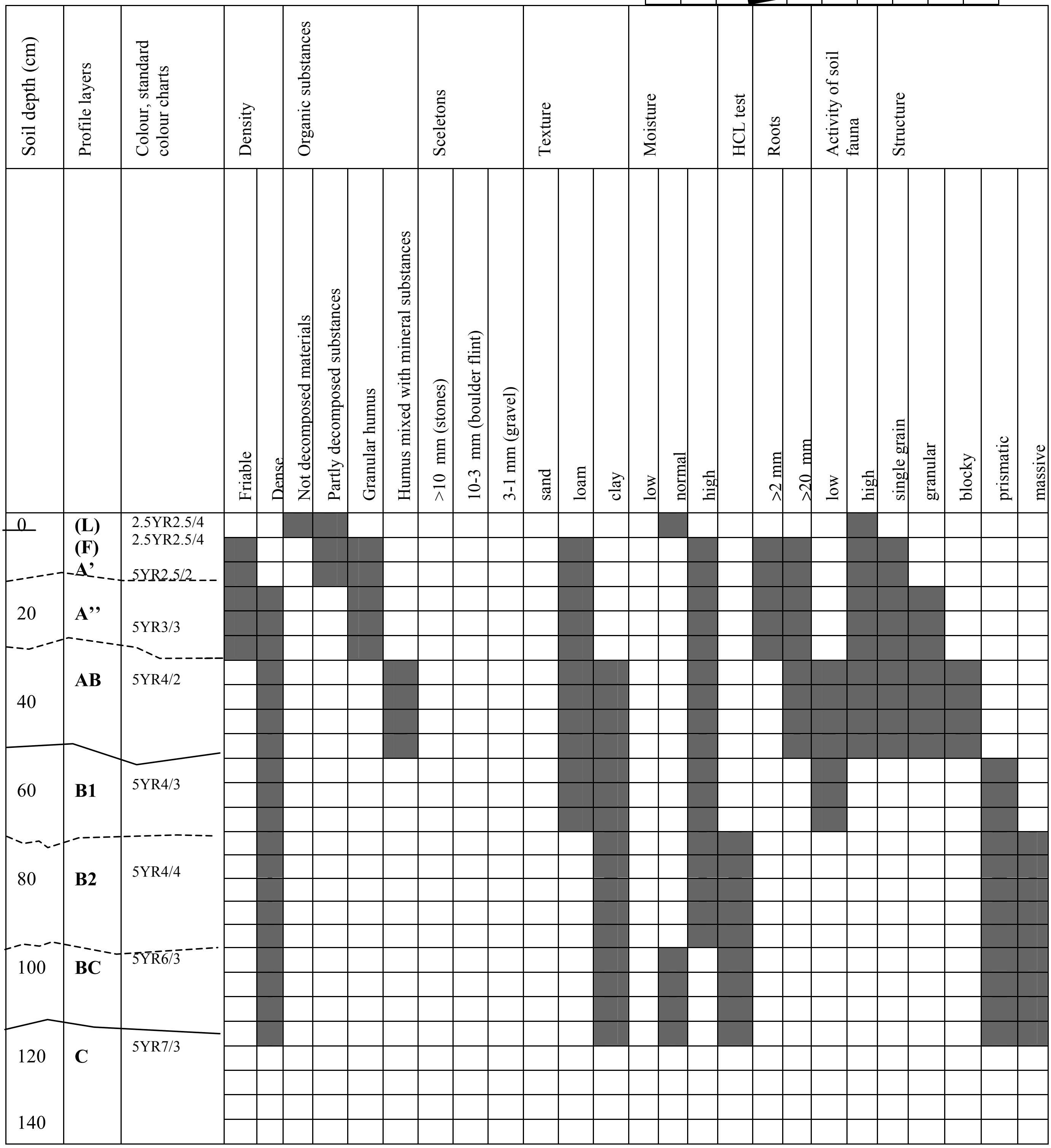


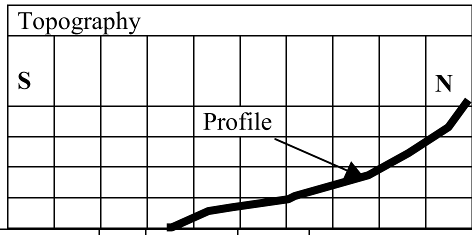
Fig. A7: *Soil profile 4*

Data: **27.06.2000**
Place: **boundary Jylandy**

Height (h.a.s.l) **2050 m**

Trial plot: **control glade near the fir plantation**
Exposition: **NE**

Geology: **loess argillaceous slates**
Steepness: **10-15°**



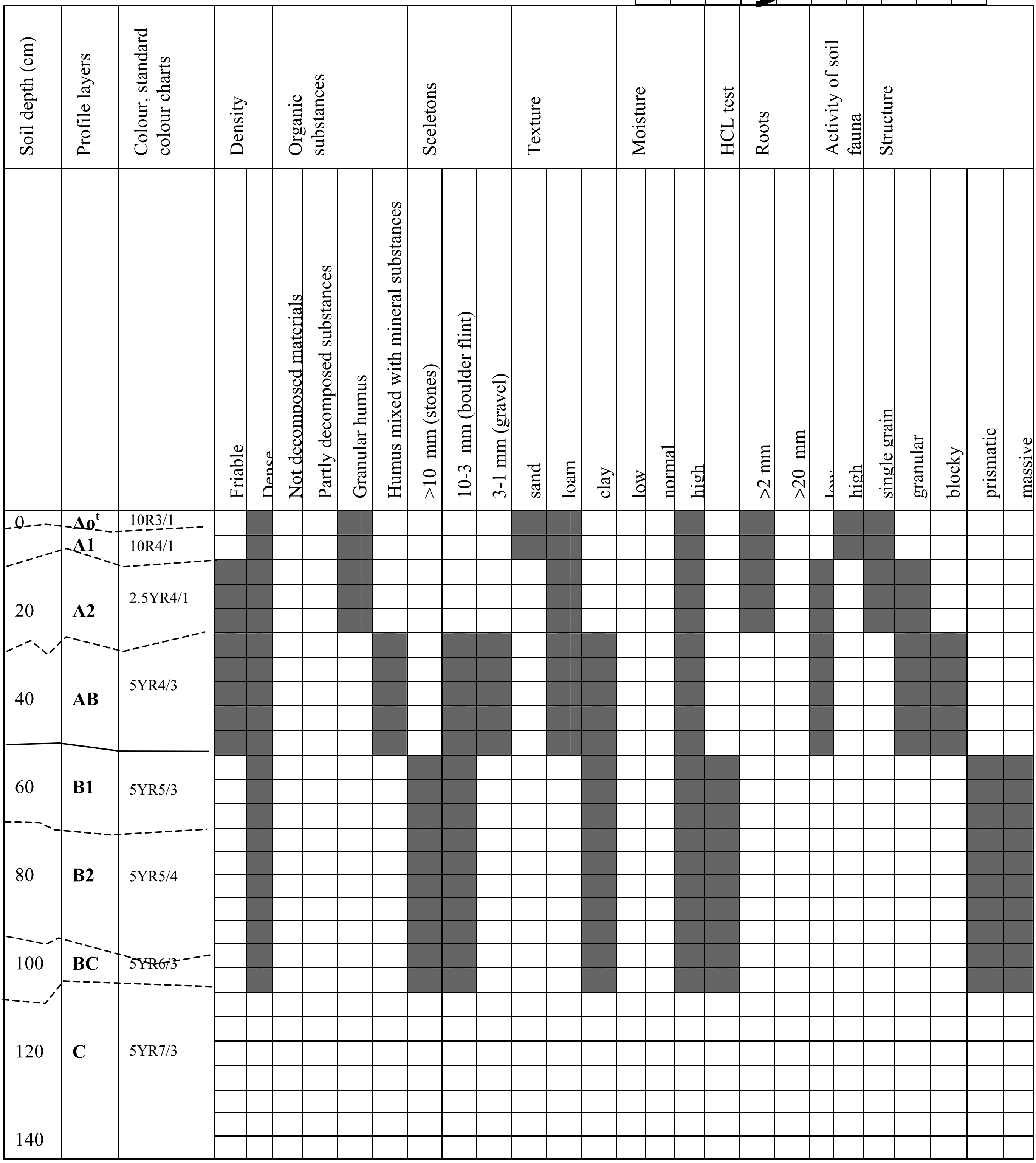


Fig. A8: *Soil profile 5*

Data: **28.06.2000**
Place: **boundary Jylandy**

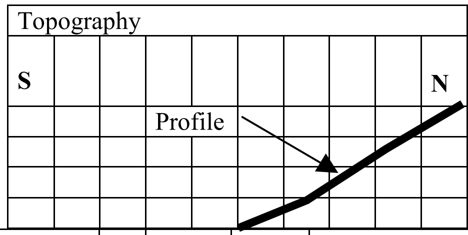
Height (h.a.s.l) : **2120 m**

Trial plot: **pine plantation**

Geology: **loess argillaceous slates**

Exposition: **NE**

Steepness: **30-35°**



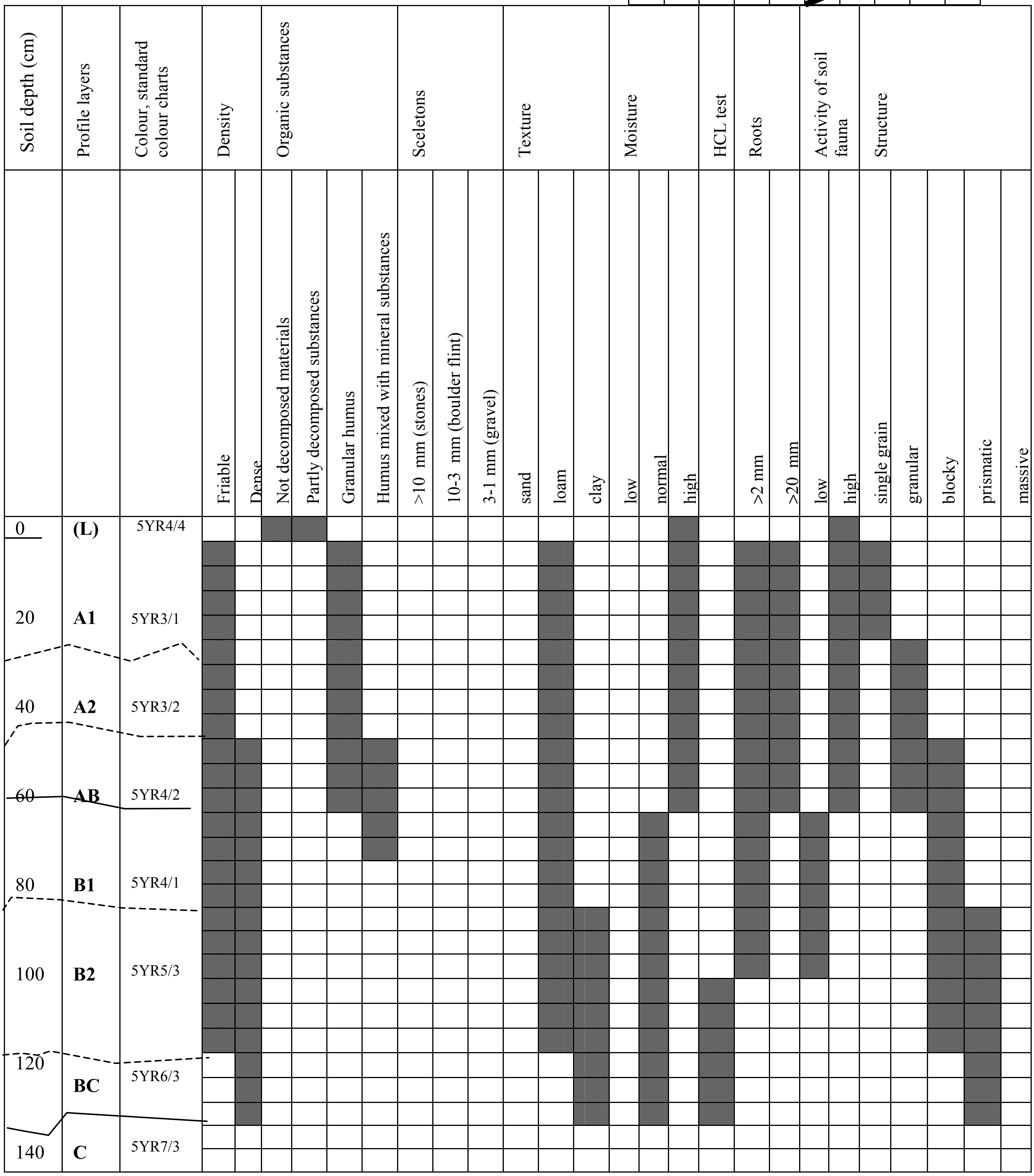


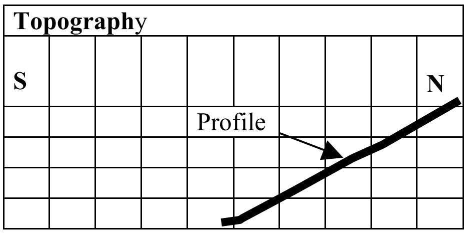
Fig A9: *Soil profile 6*

Data: **28.06.2000**
Place: **boundary Jylandy**

Height (h.a.s.l) : **2120 m**

Trial plot: **control glade near the pine plantation**
Exposition: **NE**

Geology: **loess argillaceous slates**
Steepness **30-35°**



Soil depth (cm)	Profile layers	Colour, standard colour charts	Density		Organic substances				Sceletons			Texture			Moisture			HCL test	Roots		Activity of soil fauna		Structure				
			Friable	Dense	Not decomposed materials	Partly decomposed substances	Granular humus	Humus mixed with mineral substances	>10 mm (stones)	10-3 mm (boulder flint)	3-1 mm (gravel)	sand	loam	clay	low	normal	high		>2 mm	>20 mm	low	high	single grain	granular	blocky	prismatic	massive
0	**Ao^t**	5YR2.5/2		■			■					■	■				■		■			■	■				
	A1	5YR3/1	■				■					■	■				■		■			■	■	■			
			■				■					■	■				■		■			■	■	■			
			■				■					■	■				■		■			■	■	■			
20			■	■			■						■				■		■		■		■	■			
	A2	5YR4/2	■	■			■						■				■		■		■		■	■			
			■	■			■						■				■		■		■		■	■			
40			■	■			■						■				■		■		■		■	■			
			■	■			■						■				■		■		■		■	■			
			■	■				■					■				■				■			■	■		
		5YR4/1	■	■				■					■				■				■			■	■		
60	**AB**		■	■				■					■				■				■			■	■		
			■	■				■					■				■				■			■	■		
			■	■				■					■				■				■			■	■		
80			■	■				■					■				■				■			■	■		
				■									■	■			■								■		
	B1	5YR4/2		■									■	■			■								■		
				■									■	■			■	■							■		
100				■									■	■			■	■							■		
				■										■			■	■								■	
		5YR5/2		■										■			■	■								■	
	B2			■										■			■	■								■	
120				■										■			■	■								■	
	BC		■											■			■	■									■
		5YR6/3																									
140	**C**	5YR7/3																									

Fig. A10: *Soil profile 7*

Data: **29.06.2000**

Height (h.a.s.l) : **2100 m**

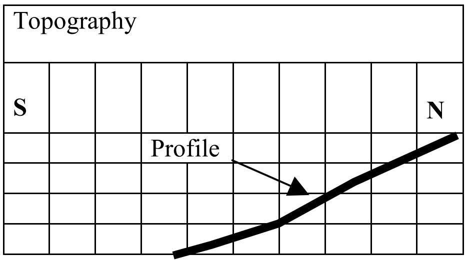
Place: **boundary Jylandy**

Trial plot: **larch plantation**

Geology: **loess argillaceous slates**

Exposition: **NE**

Steepness: **30-35°**



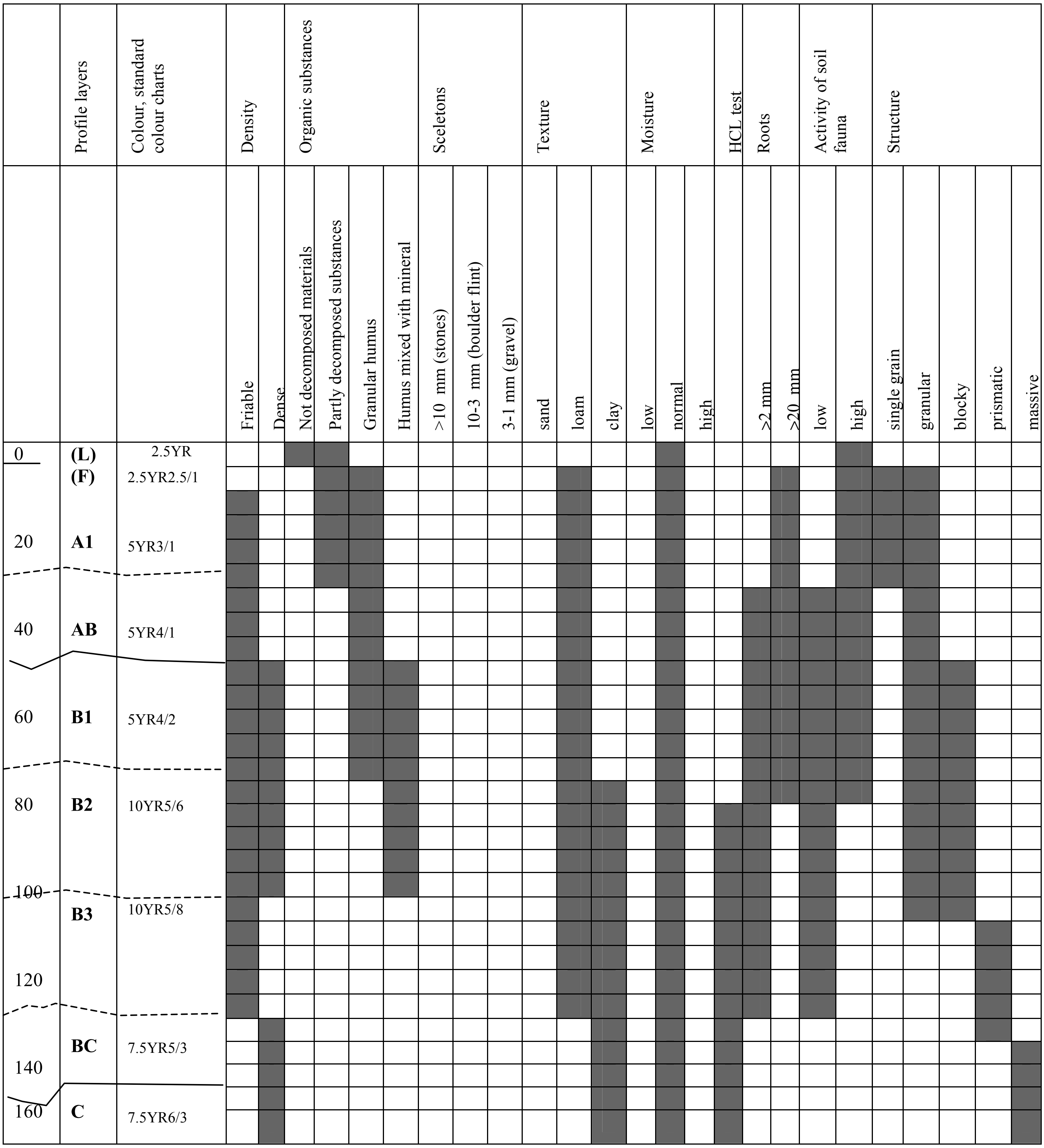


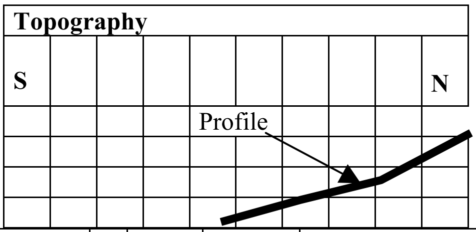
Fig A11: *Soil profile 8*

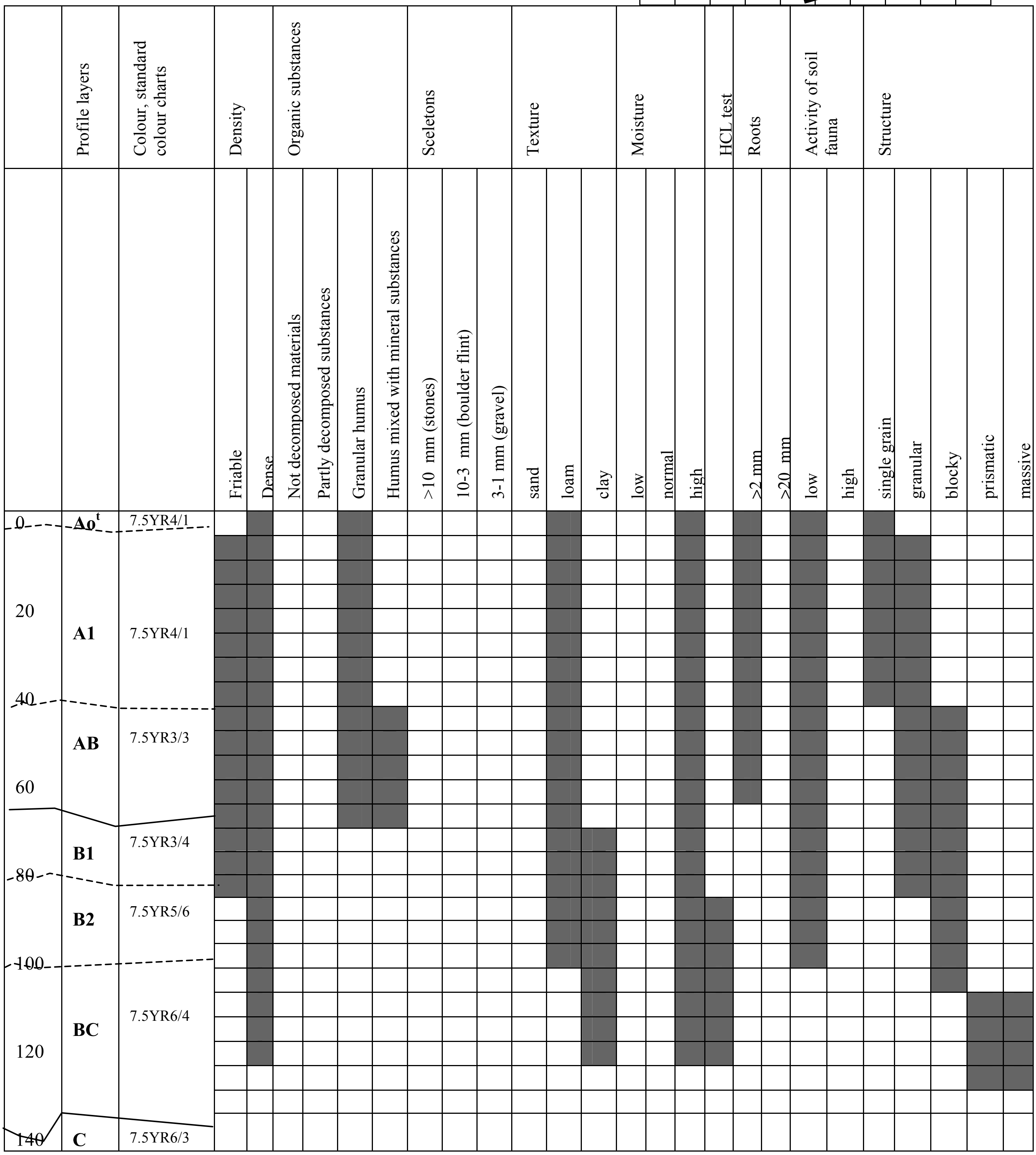
Data: **29.06.2000**
Place: **boundary Jylandy**

Height (h.a.s.l) : **2100 m**

Trial plot: **control glade near the larch plantation**
Exposition: **NE**

Geology: **loess argillaceous slates**
Steepness: **30-35°**





Tab. A5: Soil $pH_{(H2O)}$ under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary

Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH	Plot (cm)	pH
birch (7)	7,15	control (7)	8,15	fir-tree (12)	7	control (12)	6,14	pine (15)	6,05	control (15)	6,6	larch (10)	7,65	control (10)	8,17
birch (7)	7,35	control (7)	8,19	fir-tree (12)	7,15	control (12)	6,15	pine (15)	6	control (15)	6,7	larch (10)	7,7	control (10)	8,18
birch (7)	7,17	control (7)	8,25	fir-tree (12)	7,2	control (12)	6	pine (15)	6,1	control (15)	6,75	larch (10)	7,67	control (10)	8,21
mean	**7,2**		**8,2**		**7,1**		**6,1**		**6,1**		**6,7**		**7,7**		**8,2**
birch (22)	7,65	control (22)	8,35	fir-tree (20)	7,25	control (20)	6,68	pine (40)	6,45	control (40)	6,65	larch (45)	7,95	control (45)	8,27
birch (22)	7,7	control (22)	8,17	fir-tree (20)	7,36	control (20)	6,7	pine (40)	6,53	control (40)	6,57	larch (45)	8,2	control (45)	8,34
birch (22)	7,55	control (22)	8,15	fir-tree (20)	7,23	control (20)	6,68	pine (40)	6,52	control (40)	6,6	larch (45)	8,1	control (45)	8,28
mean	**7,6**		**8,2**		**7,3**		**6,7**		**6,5**		**6,6**		**8,1**		**8,3**
birch (42)	8,2	control (42)	8,43	fir-tree (40)	7,37	control (40)	6,75	pine (65)	6,53	control (65)	6,87	larch (60)	8,25	control (60)	8,45
birch (42)	8,25	control (42)	8,45	fir-tree (40)	7,42	control (40)	6,9	pine (65)	6,62	control (65)	6,85	larch (60)	8,27	control (60)	8,52
birch (42)	8,18	control (42)	8,35	fir-tree (40)	7,42	control (40)	6,7	pine (65)	6,57	control (65)	6,9	larch (60)	8,32	control (60)	8,47
mean	**8,2**		**8,4**		**7,4**		**6,8**		**6,6**		**6,9**		**8,3**		**8,5**
birch (73)	8,15	control (73)	8,37	fir-tree (60)	7,55	control (60)	8,48	pine (90)	6,75	control (90)	7,56	larch (90)	8,45	control (90)	8,75
birch (73)	8,25	control (73)	8,34	fir-tree (60)	7,63	control (60)	8,37	pine (90)	6,82	control (90)	7,59	larch (90)	8,47	control (90)	8,82
birch (73)	8,1	control (73)	8,41	fir-tree (60)	7,55	control (60)	8,45	pine (90)	6,77	control (90)	7,63	larch (90)	8,52	control (90)	8,76
mean	**8,2**		**8,4**		**7,6**		**8,4**		**6,8**		**7,6**		**8,5**		**8,8**
birch (105)	8,59	control (105)	8,49	fir-tree (80)	7,77	control (80)	8,55	pine (115)	8,1	control (115)	8,56				
birch (105)	8,6	control (105)	8,45	fir-tree (80)	7,83	control (80)	8,37	pine (115)	8,15	control (115)	8,62				
birch (105)	8,56	control (105)	8,45	fir-tree (80)	7,75	control (80)	8,39	pine (115)	8	control (115)	8,63				
mean	**8,6**		**8,5**		**7,8**		**8,4**		**8,1**		**8,6**				
				fir-tree (100)	8,42	control (100)	8,55								
				fir-tree (100)	8,37	control (100)	8,6								
				fir-tree (100)	8,38	control (100)	8,45								
mean					**8,4**		**8,5**								

Tab. A6: Aggregate size distribution (dry sieving) under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2001)

Trial plots	**Soil depth**	**Aggregate size distribution in % (sizes in mm)**								
	(cm)	**> 10**	**10-5**	**5-3**	**3-2**	**2-1**	**1-0.5**	**0.5-0.25**	**< 0.25**	**Σ 1-10**
Birch	0-22	2.05	16.5	40.85	18.2	15.3	6.90	0.16	0.04	90.85
Birch	22-42	14.72	66.67	4.96	5.51	5.58	2.46	0.03	0.07	82.72
Birch	42-73	24.52	21.05	12.84	9.55	14.9	14.04	1.05	2.05	58.34
Birch	73-105	32.8	15.5	9.9	7.9	13.5	17.0	0.2	3.2	46.8
Birch	105-125	24.46	15.19	10	8.37	14.37	16.88	4.06	6.67	47.93
Control	0-18	29.12	35.50	19.64	8.69	5.15	1.29	0.17	0.44	68.98
Control	18-40	23.03	26.72	15.48	10.73	14.31	6.2	1.59	1.94	67.24
Control	40-66	19.6	30.6	18.8	12.4	12.0	3.8	1.0	1.8	73.8
Control	66-90	19.4	26.2	14.4	10.2	12.8	6	2.6	8.4	63.6
Control	90-105	15.7	20.8	12.1	10.6	19.8	10.7	2.7	7.6	63.3
Fir	0-15	0.9	27.78	32.3	27.5	8.9	0.9	0.7	1.02	96.48
Fir	15-30	1.8	56.9	22.9	10.6	5.8	0.4	0.9	0.7	96.2
Fir	30-50	8.6	41.6	24.8	13.4	8.4	1.2	1.2	0.8	88.2
Fir	50-70	18.4	25	18.6	16.5	15	3.2	1.9	1.4	75.1

Tab. A6 continued

Trial plots	**Soil depth**	**Aggregate size distribution in % (sizes in mm)**								
	(cm)	**> 10**	**10-5**	**5-3**	**3-2**	**2-1**	**1-0.5**	**0.5-0.25**	**< 0.25**	**∑ 1-10**
Fir	70-90	15	26.9	15	11.6	14.9	7.6	3.6	5.4	68.4
Control	0-4	4.3	28.6	33.2	19	11.9	1.5	1.0	0.5	92.7
Control	4-12	4.5	33.3	31.2	17	10.8	1.9	0.9	0.4	92.3
Control	12-35	4.5	50	23.7	12.9	7.4	0.9	0.4	0.2	94.0
Control	35-50	12.4	28.4	30.3	15	10.1	1.4	1.4	1.0	83.8
Control	50-70	5.1	29.8	32.2	17.6	11.4	1.2	1.6	1.1	91
Control	70-100	20.4	26.1	16.3	16	14.8	2.7	2.3	1.4	73.2
Pine	0-30	3.09	25.9	33.27	17.9	13.4	4.94	0.45	1.05	90.47
Pine	30-42	6.85	31.65	21.5	16.25	14.35	4.95	2.5	1.95	83.75
Pine	42-60	13.2	30.4	20.6	14.6	13.8	4.2	1.6	1.4	79.4
Pine	60-80	35.9	25.3	11.8	8.9	10.9	3.9	1.8	1.6	56.9
Pine	80-120	45.9	26.0	10.5	6.5	6.7	2.5	1.0	0.9	49.7
Control	0-20	4.7	58.4	14.5	10.1	7.0	1.9	0.3	0.4	90.0
Control	20-50	30.5	33.5	12.9	8.6	8.9	2.8	1.6	1.8	63.9
Control	50-80	32.6	25.3	11.9	8.8	11.6	4.8	2.2	2.8	57.6

Tab. A6 continued

Trial plots	**Soil depth (cm)**	**Aggregate size distribution in % (sizes in mm)**								
		> 10	**10-5**	**5-3**	**3-2**	**2-1**	**1-0.5**	**0.5-0.25**	**< 0.25**	**∑ 1-10**
Control	80-100	23.6	24.8	12.7	10.5	13.5	6.1	4.0	4.8	61.5
Control	100-120	4.5	33.4	15.6	13.4	18.4	8.9	3.4	2.4	80.8
Larch	0-4	1.0	32.9	40.6	15.3	8.2	0.9	0.5	0.6	97.0
Larch	4-30	0.9	36.2	37.4	15.9	7.6	0.9	0.5	0.6	97.1
Larch	30-50	3.1	32.2	26	15.7	15	4.8	1.8	1.4	88.9
Larch	50-75	8.0	35.9	23.6	17	11.7	1.4	1.4	1	88.2
Larch	75-100	13.4	31	16.6	17.4	15	4	1.2	1.4	80.0
Larch	100-135	21.6	26	15.2	14.8	15.4	5	1.2	0.8	71.4
Control	0-2	5.5	28.5	28.3	19.4	13.3	2.8	1.4	0.8	89.5
Control	2-40	7.6	37.1	24.6	14.1	10.9	2.4	1.6	1.7	86.7
Control	40-67	30.4	33.6	12.5	6.9	7.6	4.2	2.6	2.2	60.6
Control	67-82	46.8	19.3	10.4	7.1	8.4	2.6	2.9	2.5	45.2
Control	82-100	17.6	25.8	15.9	11.8	17.8	3.2	3.1	4.8	71.3
Control	100-130	20.1	26.1	15.2	11.2	13.6	5.6	3.6	4.6	66.1

Tab. A7: Aggregate size distribution (wet sieving) under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2001)

Trial plots	**Soil depth**	**Aggregate size distribution in % (sizes in mm)**					
	(cm)	**> 5**	**5-3**	**3-1**	**1-0.25**	**< 0.25**	**≥0.25**
Birch	0-22	14	7.6	33	7.8	37.6	62.4
Birch	22-42	15.4	41.8	27.2	8	7.6	92.4
Birch	42-73	3.6	29.6	31	15.8	20	80,0
Birch	73-105	12	8.2	39.2	17.2	23.4	76.6
Birch	105-125	4.2	19.6	45.8	8.4	22	78,0
Control	0-18	50.8	25.8	14	2.6	6.8	93.2
Control	18-40	33	29.4	20.6	9.4	7.6	92.4
Control	40-66	9.4	35.6	27	14.4	13.6	86.4
Control	66-90	12.6	19.8	47.6	14.4	5.6	94.4
Control	90-105	2.2	18.6	32.4	18.6	28.2	71.8
Fir	0-15	24	28.8	28.4	3.2	15.6	84.4
Fir	15-30	65	14	12.4	2.6	6	94
Fir	30-50	45.6	19.8	19.4	6.6	8.6	91.4
Fir	50-70	35.8	10.4	24.8	14.2	14.8	85.2

Tab. A7 continued

Trial plots	Soil depth (cm)	Aggregate size distribution in % (sizes in mm) > 5	5-3	3-1	1-0.25	< 0.25	≥0.25
Fir	70-90	24.4	8.6	28.6	19.4	9	91
Control	0-4	25.2	16.8	20.4	7.4	30.2	69.8
Control	4-12	31.4	20.6	17.6	7.8	22.6	77.4
Control	12-35	35.2	10.8	20.2	10.8	23	77
Control	35-50	34	20.8	19.6	9	16.6	83.4
Control	50-70	1.8	9.8	40.6	14.2	33.6	66.4
Control	70-100	6.8	9	17.2	32.2	34.8	65.2
Pine	0-30	45.6	19.8	20.6	5.6	8.4	91.6
Pine	30-42	11.2	41	30.4	8.0	9.4	90.6
Pine	42-60	8.2	28.2	31.4	16	16.2	83.8
Pine	60-80	8	14	29.8	14.8	33.4	66.6
Pine	80-120	4.4	3.8	26	27.8	38	62
Control	0-20	45.2	23.4	16.8	4.6	10	90
Control	50-80	32.4	11	24.6	16.4	15.6	84.4

Tab. A7 continued

Trial plots	**Soil depth**	**Aggregate size distribution in % (sizes in mm)**					
	(cm)	**> 5**	**5-3**	**3-1**	**1-0.25**	**< 0.25**	**≥0.25**
Control	80-100	13.4	5.6	15.2	36	29.8	70.2
Control	100-120	3.2	7.6	26.4	23.2	39.6	60.4
Larch	0-4	25.2	16.8	20.4	7.4	30.2	69.8
Larch	4-30	31.4	20.6	17.6	7.8	22.6	77.4
Larch	30-50	35.2	10.8	20.2	10.8	23	77
Larch	50-70	34	20.8	19.6	9	16.6	83.4
Larch	70-100	1.8	9.8	40.6	14.2	33.6	66.4
Larch	100-135	6.8	9	17.2	32.2	34.8	65.2
Control	0-2	46	12.2	14.4	5	22.4	77.6
Control	2-40	58.4	6.4	15	4.8	15.4	84.6
Control	40-67	29.6	6	21.4	18.4	24.6	75.4
Control	67-82	12.2	11.8	22.4	18.8	34.8	65.2
Control	82-100	1	0.6	0.6	18.4	77.6	22.4
Control	100-130	1.4	2.4	13	23.2	60	40

Tab. A8: Soil texture analysis under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary (2001)

Trial plots	Soil depth (cm)	Distribution of particles in % (sizes in mm)						Sum of fractions <0.01
		1.0-0.25 (coarse and medium sand)	**0.25-0.05 (fine and very fine sand)**	**0.05-0.01 (coarse silt)**	**0.01-0.005 (medium silt)**	**0.005-0.001 (fine silt)**	**<0.001 (clay)**	
Birch	0-3	0.66	11.82	32.32	18.16	19.16	17.88	55.20
Birch	3-22	0.60	6.68	33.64	16.44	21.96	20.68	59.08
Birch	22-42	0.41	5.71	34.44	16.60	15.64	27.20	59.44
Birch	42-73	0.31	4.53	36.92	14.76	20.92	22.56	58.24
Birch	73-105	0.26	2.36	36.60	17.08	18.48	24.68	60.78
Control	5-18	0.70	9.58	33.28	14.48	26.88	15.08	56.44
Control	18-42	0.66	8.58	31.80	15.00	21.64	22.32	58.96
Control	42-66	0.57	5.71	33.28	14.64	21.56	24.24	60.44
Control	66-90	0.27	6.89	33.72	15.48	19.92	23.72	59.12
Control	90-105	0.34	9.82	33.44	11.92	23.12	21.36	56.40
Fir	2-15	0.35	11.29	35.36	18.64	17.20	17.16	53.00
Fir	15-30	0.28	7.76	34.40	19.20	20.44	17.92	57.56

Tab. A8 continued

Trial plots	Soil depth (cm)	Distrbution of particles in % (sizes in mm) 1.0-0.25 (coarse and medium sand)	0.25-0.05 (fine and very fine sand)	0.05-0.01 (coarse silt)	0.01-0.005 (medium silt)	0.005-0.001 (fine silt)	<0.001 (clay)	Sum of fractions <0.01
Fir	30-50	0.36	5.88	35.12	20.04	17.76	20.84	58.64
Fir	50-70	0.46	7.90	33.24	15.60	20.84	21.96	58.40
Fir	70-90	0.21	6.55	32.88	17.32	20.80	22.24	60.36
Fir	90-110	0.44	9.04	31.28	17.44	18.36	23.44	59.24
Control	4-12	1.08	18.09	33.68	16.16	17.55	13.44	47.15
Control	12-35	0.30	14.26	30.80	16.00	19.32	19.32	54.64
Control	35-50	1.50	11.42	32.00	17.28	20.12	17.68	55.08
Control	50-70	4.61	23.83	34.80	12.48	13.96	10.32	36.76
Control	70-100	6.05	22.63	32.60	12.60	13.88	12.24	38.72
Pine	3-30	1.15	15.89	40.44	15.48	13.88	13.16	42.52
Pine	30-42	1.08	7.20	42.20	16.36	18.72	14.44	49.52
Pine	42-60	1.03	5.13	40.20	15.76	15.04	22.84	53.64
Pine	60-80	1.09	4.07	36.40	15.32	20.56	22.56	58.44
Pine	80-100	3.90	9.10	36.56	13.08	15.48	21.88	50.44

Tab. A8 continued

Trial plots	**Soil depth**	**Distrbution of particles in % (sizes in mm)**						**Sum of fractions <0.01**
	(cm)	**1.0-0.25 (coarse and medium sand)**	**0.25-0.05 (fine and very fine sand)**	**0.05-0.01 (coarse silt)**	**0.01-0.005 (medium silt)**	**0.005-0.001 (fine silt)**	**<0.001 (clay)**	
Control	5-20	0.78	12.10	37.16	17.04	18.20	14.72	49.96
Control	20-50	0.50	7.18	34.04	16.76	20.92	20.60	58.28
Control	50-80	0.50	17.82	22.64	15.88	19.64	23.52	59.04
Control	80-100	0.75	10.93	13.88	31.68	19.52	23.24	74.44
Control	100-120	1.23	14.25	34.48	12.00	16.72	21.32	50.04
Larch	10-20	0.73	12.79	40.64	16.92	15.40	13.52	45.84
Larch	40-55	0.93	9.51	34.12	17.80	19.72	17.92	55.44
Larch	55-65	0.76	4.48	36.32	17.12	15.04	26.28	58.44
Larch	85-95	0.59	9.93	35.68	14.04	16.32	23.44	53.80
Larch	115-125	2.02	10.14	36.44	15.56	16.20	19.64	51.40
Control	0-30	0.21	6.35	25.52	23.56	25.52	18.84	67.92
Control	50-60	0.12	19.12	22.92	14.68	21.16	22.00	57.84
Control	70-80	0.13	7.03	34.64	16.56	18.48	23.16	58.20
Control	85-95	0.21	9.59	35.52	13.24	18.40	23.04	54.68
Control	110-120	0.29	8.07	35.40	24.52	11.12	20.60	56.24

Tab. A9: Water infiltration under birch, fir, pine and larch plantations and in the control glades in the Jylandy boundary

Trial plots	**Cumulative infiltration after definite time (mm)**						**Mean cumulative infiltration rate (mm min^{-1})**
	2 min	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	
Birch 1	450	650	810	1000	1310	1900	31.67
Birch 2	300	550	700	820	1125	1500	25.00
Birch 3	210	310	450	550	810	1290	21.50
Mean	**320**	**503.3**	**653.3**	**790.0**	**1081.7**	**1563.3**	**26.06**
Amount of water	**320**	**183.3**	**150.0**	**136.7**	**291.7**	**481.7**	
Control 1	150	200.0	210.0	240.0	290.0	400.0	6.67
Control 2	100	105.0	110.0	115.0	120.0	160.0	2.67
Control 3	150	170.0	190.0	200.0	260.0	400.0	6.67
Mean	**133.3**	**158.3**	**170.0**	**185**	**223.3**	**320**	**5.33**
Amount of water	**133.3**	**25.0**	**11.7**	**15.0**	**38.3**	**96.7**	
Fir 1	400.0	780.0	1280.0	1680	2490	3650	60.83
Fir 2	320.0	640.0	1000.0	1350	2160	3450	57.50
Fir 3	320.0	650.0	1010.0	1360	2100	3190	53.17
Mean	**346.7**	**690.0**	**1096.7**	**1463.3**	**2250.0**	**3430.0**	**57.17**
Amount of water	**346.7**	**343.3**	**406.7**	**366.7**	**786.7**	**1180.0**	
Control 1	220.0	380.0	540.0	710.0	1130.0	1920.0	32.00
Control 2	350.0	650.0	910.0	1150.0	1750.0	2730.0	45.50
Control 3	180.0	250.0	380.0	480.0	830.0	2000.0	33.33
Mean	**250.0**	**426.7**	**610.0**	**780.0**	**1236.7**	**2216.7**	**36.94**
Amount of water	**250.0**	**176.7**	**183.3**	**170.0**	**456.7**	**980.0**	

Tab. A9 continued

	Cumulative infiltration after definite time (mm)						Infiltration rate (mm min^{-1})
Trial plots	**2 min**	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	
Pine 1	250.0	420.0	700.0	880.0	1380.0	2000.0	33.33
Pine 2	280.0	550.0	700.0	810.0	1100.0	1520.0	25.33
Pine 3	310.0	550.0	800.0	1050.0	1650.0	2290.0	38.17
Mean	**280.0**	**506.7**	**733.3**	**913.3**	**1376.7**	**1936.7**	**32.28**
Amount of water	**280.0**	**226.7**	**226.7**	**180.0**	**463.3**	**560.0**	
Control 1	220.0	310.0	480	650	950	1300	21.67
Control 2	150.0	190.0	210	250	350	550	9.17
Control 3	130.0	150.0	150	160	180	210	3.50
Mean	**166.7**	**216.7**	**280.0**	**353.3**	**493.3**	**686.7**	**11.44**
Amount of water	**166.7**	**50.0**	**63.3**	**73.3**	**140.0**	**193.3**	
Larch 1	1000	1350	2100	2700	3550	5400	90.00
Larch 2	350	720	1150	1410	2050	2750	45.83
Larch 3	670	1300	3900	5200	7600	9850	164.17
Mean	**673.3**	**1123.3**	**2383.3**	**3103.3**	**4400**	**6000**	**100.00**
Amount of water	**673.3**	**450.0**	**1260.0**	**720.0**	**1296.7**	**1600**	
Control 1	180	210	280	350	520	800	13.33
Control 2	120	125	130	130	135	140	2.33
Control 3	150	180	190	220	290	420	7.00
Mean	**150**	**171.7**	**200.0**	**233.3**	**315.0**	**453.3**	**7.56**
Amount of water	**150**	**21.7**	**28.3**	**33.3**	**81.7**	**138.3**	

CURRICULUM VITAE

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1. Uzakabaeva J. (2001) Effect of forest plantations on soils in east Priissikkulia. Forestry and silviculture investigation in Kyrgyzstan, Bishkek, Kyrgyzstan: 81-87 /in Russian/

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